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AMMUNITION COST RESEARCH: MEDIUM-BORE AUTOMATIC CANNON AMMUNITION

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AMMUNITION COST RESEARCH: MEDIUM-BORE AUTOMATIC CANNON AMMUNITION

SEPTEMBER 1975

TECHNICAL REPORT

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13. ABSTRACT

At the complete round level of detail, statistically valid cost estimating relationships (CER's) for independent parametric cost estimates of ammunition investment costs have been difficult to construct. The long life span of ammunition items reduces the number and range of data points available for a given weapon system class (e.g., tank main armament). To counter this problem, a research project has been undertaken to relate physical round performance to component cost (primers, propellants, projectiles, etc.). The report for medium-bore automatic gun ammunition represents the first of three reports resulting from this project. This report demonstrates how component-level CER's and cost models can be used to independently estimate ammunition investment costs with much greater statistical validity than has been obtained with past approaches.

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DISCLAIMER

The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

AMMUNITION COST RESEARCH:

MEDIUM-BORE AUTOMATIC CANNON AMMUNITION

October 1975

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SECTION I

INTRODUCTION

A. BACKGROUND

Preparation of independent parametric cost estimates (IPCE's) for new ammunition proposals has been difficult because of the absence of a comprehensive data base normalized in accordance with consistent and substantiated learning curve assumptions. To compound the difficulty, statistical development of cost estimating relationships (CER's) has traditionally been confined to narrow bands of components or complete rounds. Use of these narrow bands has caused a loss of data points and a reduction in the statistical quality of the results, as well as a limitation of the range of usage. This narrow focus was the natural result of the past emphasis given to estimating costs for specific weapon systems as they reached critical decision milestones rather than planning broad based, long-range studies which addressed multiple systems with many potential ammunition uses.

To correct this problem, the ammunition cost research project was chartered by the Cost Analysis Directorate of the Office of the Comptroller of the Army. The Cost Analysis Directorate charged the Army Materiel Command (AMC) with the responsibility for this study on 20 Mar 75. In turn, AMC assigned the task to the Cost Analysis Division, Headquarters, US Army Armament Command (ARMCOM) on 1 Apr 75.

B. GENERAL APPROACH

The purpose of this study is to develop investment cost-estimating tools for ammunition which will facilitate independent cost estimates. It is not intended that the results of the study be used for current procurement actions. The study is to support decision making early in the acquisition phase. The developed tools are expected to feature the use of statistical methods to predict ammunition costs from physical performance characteristics. These tools, regardless of form, must be applicable to prevalent types and calibers of ammunition produced at various program quantities so that wide ranges of ammunition proposals can be estimated easily and independently.

Because of the lack of success in structuring CER's at the total round level, the ammunition cost research study has been conducted at the component level of detail. Results of the component CER's can be summed to obtain the total program cost for ammunition.

Priority was given to the use of hard procurement data. The data were selected because they represent actual procurement practices. Data adjudged by price analysts as being unsuitable for procurement uses were excluded. The exclusions were made prior to the beginning of the cost-research project in a completely independent action. When hard procurement data were not available because of the obsolescence of an ammunition item, a cost estimate was obtained from the responsible engineering agency to fill out the independent variable continuum.

A statistical analysis was performed using the Stanford University Biomedical Computer Program to develop the CER's. The learning analysis, or cost improvement curve analysis, was performed using the Missile Command (MICOM) approach to calculating the unit learning curve. Of major importance in the learning analysis are the issues of level-off cost, and the impacts of breaks and rate changes in production output.

The study will be published in three volumes. Volume I covers medium-bore automatic cannon ammunition (20mm-60mm); volume II will cover artillery ammunition which includes tank main armament, field artillery, mortars, and recoilless-rifle ammunition; and volume III will cover small arms ammunition (less than 20mm).

C. ACKNOWLEDGEMENTS

While the Cost Analysis Division, HQ, ARMCOM performed a central role in data collection and study coordination, completion of the project would not have been possible without the suggestions and assistance provided by HQ, ARMCOM Directorates of Research, Development, and Engineering; Procurement and Production; Quality Assurance; Materiel Management; Maintenance; and Transportation and Traffic Management. Special estimating and data collection efforts were provided by the employees at Frankford and Picatinny Arsenals to fulfill the broad scope of study. Assistance was also readily provided by the project manager for Production Base Modernization in the area of industrial production facilities costs.

Valuable data and advice were received from both the Department of the Air Force and the Department of the Navy.

Several project team members outside the Cost Analysis Division assisted and advised the project principles. John McAloon, Melvin Drucker, Capt. John McLaughlin, Alvis Taylor, Duane Johnson, and Robert Wilson from ARMCOM functional directorates were invaluable sources of information. Kenneth Rubin of Picatinny Arsenal and Edward Dougherty of Frankford Arsenal deserve specific recognition. From the office of the Project Manager for Munitions Production Base Modernization and Expansion, Charles Carrigan's efforts are appreciated.

From the ARMCOM Comptroller's Office Jo Ellen McClure deserves special recognition for her assistance in statistical analysis. Also, recognition is due to Catherine Cooney, without whose perseverance and editorial abilities this project would have suffered. And, finally, Rebecca Bennett, Martha Clark, and Irene DeClercq are commended for their cooperation and their skillful typing and diligence.

SECTION II

STUDY RESULTS

A. GENERAL ESTIMATING METHODOLOGIES

The primary approach proposed by this study for developing investment cost IPCL's is mathematical modeling and CER's. The study results successfully demonstrate that component level development of cost models and CER's should be used rather than attempting to prepare such models and relationships at the total round level.

While the component approach does not eliminate difficulties when advances in ammunition technology are incorporated into a new ammunition proposal, structuring the estimate at the component level limits these problems to the components involved in the change. When using total round level CER's and when faced with a new kind of component, such as a telescoped cartridge case, the estimator must reduce the reliability of the total estimate with a complexity factor or abandon use of the CER entirely. With component CER's the estimator need only adopt alternate estimating techniques for the components that are unique.

This study does not attempt to give specific guidance for handling new and unused technologies. It is not possible to forsee all problems, or to predict their solutions. However, on the basis of shortages in the data base and from the experiences gained in developing the models and CER's, certain problems can be forseen. They are:

1. the lack of Army experience with aluminum cases, telescoped cases, discarding sabot projectiles, dual-purpose HE projectiles, and depleted uranium penetrators.

2. the general difficulty of fuze estimating, which not only includes technological changes with the introduction of electronic componentry, but also seems to lack strong cost drivers.

This report is the first of three volumes on ammunition costs. The results of this report are not intended to be final. Revisions to the medium-bore models and CER's can be expected in volumes II and III as more time data become available.

The remainder of section II is split between reporting the results for initial production facilities and presentation of the CER's and factors prepared for ammunition component production costs. The use of CER's is illustrated with an example estimate. The IPF model is too complex for manual illustration.

B. NONRECURRING INVESTMENT

Prior to preparation of an independent parametric cost estimate (IPCE) of initial production facilities IPF, it is essential to obtain a clear statement of machinery requirements for the family of ammunition to be produced. To obtain this requirements statement, it is first necessary to determine the mobilization plan for the ammunition being introduced to the Army. Then it is necessary to determine whether the existing base of machinery is sufficient to meet the mobilization plan. If this base is not sufficient, then the short fall must be specified at the component level of detail. Only then can a realistic IPCE be prepared.

The resulting mobilization output rate for each component and the corresponding short fall from the desired output rate must be the agreed upon basis for both the IPCE and the Baseline Cost Estimate (BCE) being compared. Given that the outputs are properly defined, it was determined that cost modeling is the best way to independently estimate the machinery required to support a new medium-bore ammunition family.

The proposed cost estimating model, definitions of the mathematical notation used, and accompanying rationale and procedural explanations are included in section IIIB. Because of the complexity of the model, its supporting data base, and the level of detail at which cost estimates are generated, it is intended that the model be exercised by computer. Therefore, this section is confined to a general description of the coverage provided by the model and the estimating algorithm. A later volume of the ammunition cost-research study will incl[illegible] a computer program written in the FORTRAN IV programming language.

The estimating model covers the cost elements of industrial production equipment (IPE), special initial tooling, and test and measuring equipment for medium-bore ammunition at the component and load, assemble, and pack (LAP) levels over two size ranges. Separate estimates can be obtained for the last two cost elements if the estimate guidance precludes the inclusion of IPE. The components and size ranges covered are shown in the following table.

NONRECURRING INVESTMENT COST MODEL COVERAGE

	20-30mm	Over 30mm -60mm
1. IPE		
a. Projectile (HE, AP, and TP)	X	X
b. Link	X	
c. Box	X	
d. LAP	X	X
e. Cartridge Case	X	X
f. Fuze	X	X

	20-30mm	Over 30mm -60mm
2. INITIAL TOOLING		
a. Projectile (HE, AP, and TP)	X	X
b. Link	X	
c. Box	X	
d. LAP	X	X
e. Cartridge Case	X	X
3. TEST AND MEASURING EQUIPMENT		
a. Projectile (HE, AP, and TP)	X	X
b. Link	X	
c. Box	X	
d. LAP	X	X
e. Cartridge Case	X	X
f. Fuze	X	X

Once the mobilization plan has been determined, and the IPE shortfall in terms of scheduled numbers of rounds has been specified at the component level, the annual production quantity of each component requiring IPE or initial tooling and test and measuring equipment is used as input to the estimating model. The required additional inputs are the assumed number of production shifts per day, projectile length and diameter, cartridge case length, and number of rounds per box.

An estimating data base is included in the model as matrices which provide listings of IPE, equipment-unit costs, equipment-production capacities per shift, and average unit-tooling costs per equipment item. The matrices are shown in section IIIB as Tables III-2 through III-13. Estimates of test and measuring equipment are included in the model also.

Cost estimates are obtained through the solution of a series of cost equations for each component and LAP. By means of the equations, the estimating model performs the following:

1. The number of machines required is estimated based upon:

    a. annual production requirements (inputs to the model).
    b. the assumed number of shifts (inputs to the model).
    c. equipment item capacity per shift (included in the data base).
    d. the number of rounds per box when boxes are necessary (input to the model).
    e. for ammunition over 30mm to 60mm, the model selectively applies dimensional adjustments, employing cartridge-case and, or projectile dimensions (inputs) for size variations which affect equipment-production capacities.

2. The total cost of individual equipment items is estimated based on the number of machines required ([illegible]) and the equipment item unit cost (data base).

3. The estimated cost of all equipment required for each component and LAP is summarized. The estimated cost of test and measuring equipment (data base) is added, and allowances are applied as applicable for transportation, installation, layaway, and miscellaneous material handling equipment included in the cost equations.

4. The cost of the initial tooling for each equipment item is estimated based on the number of machines required and the average unit-tooling cost per equipment item (data base).

5. The estimated cost of initial tooling for all equipment required for each component and LAP is summarized.

C. RECURRING INVESTMENT

1. Estimating Parameters

The recurring investment portion of the study is confined to the contractor costs and excludes in-house engineering and quality assurance support. These costs are a minor factor of total life cycle costs and are, therefore, not a particular problem for the estimator when preparing an IPCE.

A further deterent to preparing estimating statistics covering these costs is the absence of an accounting system which collects support costs allocated to the procurement of complete rounds and components.

The CER's that result from this study are primarily supported by hard procurement data and engineering estimates. The hard data cover procurements from 1957 through 1975. The collection of data was conducted in accordance with the procedures outlined in section IIIC. Composite learning was prepared by component and is presented in detail in section IIID. Component production CER's and cost factors are recommended in accordance with the findings of section IIIE. Finally, a transportation cost CER is suggested in accordance with section IIIF.

The recommended composite learning rates and cost predictors for ammunition recurring costs are:

LAP   Composite learning rate is 100 percent.

HE and HEAT

$$\ln Z = -6.8639 + 2.1143 \ln X$$

where: Z = Estimated unit cost in FY-74 dollars
X = Bore size in millimeters

AP

$$\ln Z = 2.7627 - 0.001550\, X + 0.3127 \ln Y$$

where: Z = Estimated unit cost in FY-74 dollars
X = Average annual production rate in thousands
Y = Projectile mass

TP

$$\ln Z = 4.1000 - 0.3247 \ln X + 0.6453 \ln Y$$

where: Z = Estimated unit cost in FY-74 dollars
X = Average annual production rate in thousands
Y = Projectile mass

PROJECTILE   Composite learning rate is 92.6 percent.

HE

$$\ln Z = -1.6983 + 1.3739 \ln X$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Bore size in millimeters

AP

$\ln Z = 3.9918 + 1.7971 \ln X$

where: Z = Estimated theoretical first unit cost in FY 74 dollars

X = Bore size in millimeters

HP

$\ln Z = 5.5868 + 2.1305 \ln X$

where: Z = Estimated theoretical first unit cost in FY 74 dollars

X = Bore size in millimeters

EXPLOSIVE FILL Composite learning rate is 100 percent.

HE

$\ln Z = -13.7931 + 3.0791 \ln X$

where: Z = Estimated unit cost in FY 74 dollars

X = Bore size in millimeters

HEAT

$\ln Z = -12.3829 + 2.6706 \ln X$

where: Z = Estimated unit cost in FY 74 dollars

X = Bore size in millimeters

HEPT

$\ln Z = -3.7946 + 0.05190\ X$

where: Z = Estimated unit cost in FY 74 dollars

X = Bore size in millimeters

CASE Composite learning rate is 91.3 percent.

CASE BRASS

$\ln Z = 0.6853 + 0.02671\ X + 0.5731\ Y$

where: Z = Estimated theoretical first unit cost in FY 74 dollars

X = Bore size in millimeters

Y = Projectile mass

CASE STEEL

$\ln Z = 1.0625 + 0.02063\ X + 0.2022\ Y$

where: Z = Estimated theoretical first unit cost in FY 74 dollars

X = Bore size in millimeters

Y = Projectile mass

PROPELLANT Composite learning rate is 100 percent.

$\ln Z = -10.5840 + 0.01571\ X + 0.7416 \ln Y$

where: Z = Estimated unit cost in FY 74 dollars

X = Bore size in millimeters

Y = Kinetic energy

PRIMER Composite learning rates are 89.7 percent and 80.3 percent for percussion and electric respectively.

PERCUSSION

$LnZ = 2.7957 - 2.2678\ LnX + 1.3338\ LnY$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application momentum

ELECTRIC

$LnZ = -14.1220 + 4.0538\ LnX - 0.9031\ LnY$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

LINK Composite learning rate is 100 percent.

Bore Size	Unit Cost in FY-74 dollars
7.62mm	$0.0127
12.7mm	0.0467
20mm	0.2413
40mm	0.2645

FUZE Composite learning rate is 91.1 percent.

PD

$LnZ = 14.0768 - 2.2258\ LnX + 1.0590\ LnY$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

BD

$LnZ = 0.6493 + 0.5905\ LnX + (2.0698 \times 10^{-7})\ Y$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application kinetic energy

PIBD

$LnZ = -52.3486 + 11.5814\ LnX - 4.0205\ LnY$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

TRANSPORTATION

$LnZ = 1.5879 + 1.0140\ LnX$

where: Z = Estimated unit cost in FY-75 dollars
X = Projectile mass

2. Development of a Procurement Plan for the Family of Ammunition.

Independent parametric cost estimates (IPCE's) are based upon historical cost data and those factors that accomplish the mission of the system. One of these factors that must be considered during the IPCE is the procurement plan for the family of ammunition being studied.

The plan must be for the complete life cycle of the system using the ammunition. In developing the plan, higher headquarters should provide guidance to ascertain levels of procurements. Before preparing the IPCE, it is necessary to answer the following questions:

a. What will the authorized acquisition objectives (AAO's) be for each round used by the system?

b. How many years of procurement will be required to fill the AAO?

c. What will the yearly rate of consumption be for each round used?

d. What will the yearly procurement rates be to maintain existing AAO levels?

Special emphasis for procurement planning is addressed in Section IV Special Findings and Recommendations.

3. Use of CER's to Estimate Total Costs

Use of the preferred CER's is illustrated with this detailed example of estimating the total ammunition recurring cost using the cost predictors and composite learning rates presented in section IIC1. Since the recurring cost parameters are presented at the ammunition component level, the first step in the procedure is to estimate the total cost of each component. The total ammunition recurring cost is the sum of the total component costs.

Suppose a cost estimate is required for two 30mm rounds of ammunition including a quantity of 10 million HE rounds designated by M100 and 20 million TP rounds designated by M200. The annual production rates are 4 million and 8 million for the M100 and M200 respectively. The M100 incorporates a point-detonating fuze. Both rounds incorporate the same cartridge case. The physical and performance characteristics of the two rounds are as follows:

	M100 HE	M200 TP
Bore size	30mm	30mm
Projectile mass (M)	0.030	0.020
Muzzle velocity (V)	3,000 fps	3,000 fps
Momentum (MV)	90	60
Kinetic energy ($0.5MV^2$)	135,000	90,000
Case	Brass	Brass

The component total costs are estimated as follows:

LAP

HE

$$\begin{aligned} \text{Ln}Z &= -6.8639 + 2.1143\ \text{Ln}X;\ X = \text{Bore size(mm)} \\ &= -6.8639 + 2.1143\ \text{Ln}30 \\ &= 0.3273 \\ Z &= \$1.387 \text{ per round} \end{aligned}$$

The total LAP cost for the M100 is $1.387 (10,000,000) = $13,870,000

TP

$$\begin{aligned} \text{Ln}Z &= 4.1000 - 0.3247\ \text{Ln}X + 0.6453\ \text{Ln}Y;\ X = \text{Annual production rate (K)}, \\ &\quad Y = \text{Projectile mass} \\ &= 4.1000 - 0.3247\ \text{Ln}8{,}000 + 0.6453\ \text{Ln}0.020 \\ &= -1.3426 \\ Z &= \$0.261 \text{ per round} \end{aligned}$$

The total LAP cost for the M200 is $0.261 (20,000,000) - $5,220,000

PROJECTILE

HE

$\ln Z = -1.6983 + 1.3739 \ln X$; X = Bore size(mm)
$= -1.6983 + 1.3739 \ln 30$
$= 2.9746$
$Z = \$19.582$ for the first unit

Using a 92.6 percent learning rate, the total projectile cost for the M100 is $36,855,500.

TP

$\ln Z = -5.5868 + 2.1305 \ln X$; X = Bore size(mm)
$= -5.5868 + 2.1305 \ln 30$
$= 1.6595$
$Z = \$5.257$ for the first unit

Using a 92.6 percent learning rate, the total projectile cost for the M200 is $18,324,200.

EXPLOSIVE FILL

HE

$\ln Z = -13.7934 + 3.0791 \ln X$; X = Bore Size(mm)
$= -13.7934 + 3.0791 \ln 30$
$= -3.3208$
$Z = \$0.036$ per round

The total fill cost for the M100 is $0.036 (10,000,000) = $360,000

CASE

HE and TP-BRASS

$\ln Z = 0.6833 + 0.02674\ X + 0.5731\ Y$; X = Bore size(mm), Y = Projectile mass
$= 0.6833 + 0.02674(30) + 0.5731(0.030)$
$= 1.5027$
$Z = \$4.494$ for the first unit

Using a 91.3 percent learning rate, the total cost cost for the M100 and M200 is $34,283,600.

PROPELLANT

HE

$\ln Z = -10.5840 + 0.01571\ X + 0.7416 \ln Y$; X = Bore size(mm), Y = Kinetic Energy
$= -10.5840 + 0.01571(30) + 0.7416 \ln 135{,}000$
$= -1.3522$
$Z = \$0.259$ per round

The total propellant cost for the M100 is $0.259 (10,000,000) = $2,590,000.

TP

$$\ln Z = -10.5840 + 0.01571(30) + 0.7416\ \ln 90{,}000$$
$$= -1.6528$$
$$Z = \$0.192 \text{ per round}$$

The total propellant cost for the M200 is \$0.192 (20,000,000) = \$3,840,000

PRIMER

HE and TP-PERCUSSION

$$\ln Z = 2.7957 - 2.2678\ \ln X + 1.3338\ \ln Y;\ X = \text{Bore size(mm)},\ Y = \text{Momentum}$$
$$= 2.7957 - 2.2678\ \ln 30 + 1.3338\ \ln 90$$
$$= 1.0843$$
$$Z = \$2.957 \text{ for the first unit.}$$

Using an 89.7 percent learning rate, the total primer cost for the M100 and M200 is \$7,071,100.

LINK

Based upon historical unit costs of \$0.2413 for 20mm links and \$0.2645 for 40mm links, a 30mm link is estimated to cost \$0.253. The total link cost for the M100 and M200 assuming 30 million links is \$0.253 (30,000,000) = \$7,590,000.

FUZE

HE-PD

$$\ln Z = 14.0768 - 2.2258\ \ln X + 1.0590\ \ln Y;\ X = \text{Bore size(mm)},\ Y = \text{Projectile mass}$$
$$= 14.0768 - 2.2258\ \ln 30 + 1.0590\ \ln 0.030$$
$$= 2.7930$$
$$Z = \$16.330 \text{ for the first unit}$$

Using a 91.1 percent learning rate, the total fuze cost for the M100 is \$21,595,700.

TRANSPORTATION

HE

$$\ln Z = 1.5879 + 1.0140\ \ln X;\ X = \text{Projectile mass}$$
$$= 1.5879 + 1.0140\ \ln 0.030$$
$$= -1.9677$$
$$Z = \$0.140 \text{ per round}$$

The total transportation cost in FY-75 dollars for the M100 is \$0.140 (10,000,000) = \$1,400,000.

The M100 transportation cost in FY-74 dollars is 0.83(\$1,400,000) = \$1,162,000.

$$\begin{aligned} \ln Z &= 1.5879 + 1.0140 \ln 0.020 \\ &= -2.3789 \\ Z &= \$0.093 \text{ per round} \end{aligned}$$

The total transportation cost in FY 75 dollars for the M200 is $0.093 (20,000,000) = $1,860,000.

The M200 transportation cost in FY 74 dollars is 0.83 ($1,860,000) = $1,543,800.

The total ammunition recurring cost in FY-74 dollars by round is summarized below. The case, primer, and link total costs are apportioned to the M100 and M200 rounds based upon the quantity of each round.

	(Costs in millions)	
	M100 HE	M200 TP
LAP	$13.870	$ 5.220
Projectile	36.856	18.324
Explosive Fill	0.360	NA
Case	11.128	22.856
Propellant	2.890	3.840
Primer	2.357	4.714
Link	2.530	5.060
Fuze	21.596	NA
Transportation	1.162	1.544
TOTAL	$92.749	$61.558

The total ammunition recurring cost is estimated at $154.307 million in FY-74 dollars.

SECTION III

STUDY METHODOLOGY

A. SPECIAL AMMUNITION PROCUREMENT CONSIDERATIONS

The uniqueness of ammunition procurement practices is attributed to the number of manufacturers involved. It is not uncommon to find a mixture of contractor owned contractor operated (COCO) plants, Government owned contractor operated (GOCO) plants, and Government owned Government operated (GOGO) arsenals providing components that will become an integral part of an ammunition round. The schematic in this section depicts the type of producers involved in manufacturing ammunition.

The bulk of production, which includes small arms ammunition items, artillery and mortar rounds, bombs, and fuzes, is done by GOCO plants. Basically, ammunition plants are classified into five categories:

a. Load, Assemble, Pack (LAP)

b. Propellants and explosives (P&E)

c. Small arms ammunition (SAA)

d. Metal parts (MPTS)

e. A plant with more than one of the above categories or multi-product use.

The types of contracts awarded to a plant vary. The LAP, P&E, SAA and multi-purpose plants operate under a cost-reimbursable contract with either fixed or incentive fee. The MPTS plants operate under a firm-fixed-price contract.

Because there is no single producer of the components that are used in the ammunition market, estimating the price is difficult. Consequently, the likelihood of incurring many different price combinations exists. For example, assume that 15 manufacturers are capable of producing components needed for a specific ammunition round. Using various combinations of producers can result in 288 different price combinations. Price combinations and the uncertainty of when inventory costs were incurred make it difficult to estimate the exact price of an ammunition round. Certain components may be procured two years before becoming an integral part of the round. The complete cost for the end item can be determined only when consideration is given to costs incurred by all producers involved in the manufacturing process. It is for this reason that individual components have been costed separately in this study.

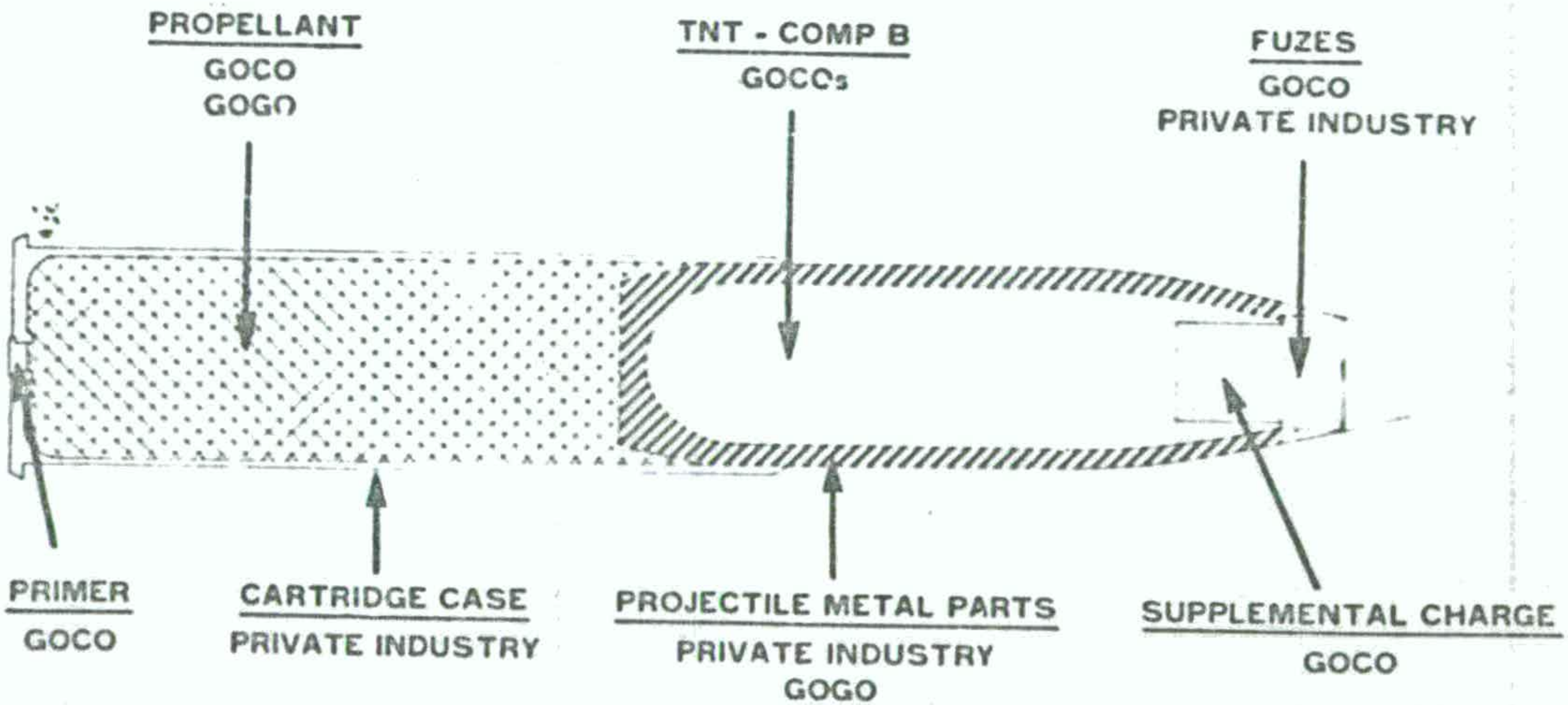
The productive orientation of ammunition at the component level influences this project and other estimators in both the IPF and production costs.

In the IPF area the industrial production base for mobilization is established, maintained, modernized and expanded on the bases of component demand. The completed round is important only to the extent that it contributes, along with other total rounds, to the

demand of the particular component. The Army does not provide TNT capacity for the M1 105mm HE howitzer projectile. Capacity is based upon total TNT demand. The consequences of this special consideration are that the preparer of cost models or IPCE's must make certain that the IPE involved considers the marginal increase in capacities and does not duplicate capacities that are already available in the industrial production base for ammunition.

In the production cost area these special considerations probably have the largest impact on the cost estimator. First, the data collection problems are greatly complicated because many manufacturers may have produced a component within a given round. Second, assuming that the first collective problem is solved and the data are cross referenced and properly normalized for inflation, the estimator must determine the most likely learning rate from a myriad of manufacturers, producing over widely varying time periods and output rates. Finally, the estimating procurement method cannot possibly be duplicated in reality when the ammunition is finally procured because of the artificiality of the estimating assumptions. The following portions of section III should be read in light of these special procurement considerations.

HIGH EXPLOSIVE COMPLETE AMMUNITION ROUND



B. INITIAL PRODUCTION FACILITIES (IPF)

The nonrecurring investment cost elements, for which equations are provided in the IPF cost model, are shown in Table III-1 and are keyed to the methodology and rationale in this section. In addition to the total nonrecurring investment cost, the model provides for the calculation of each of the cost elements shown in the table, including industrial production equipment (IPE), initial tooling, and test and measuring equipment for each of the ammunition components shown. All costs are in thousands of FY-74 dollars.

To facilitate tracking the equations used in the cost model, the order of sequence in which they are solved for each component is shown in Tables III-14 and III-15. The equations for 20mm-30mm components are numbered in the order in which they are used in the solution of each component-submodel; however, for submodels over 30mm-60mm, the equations are numbered in the order in which they are used in the submodels in which they first appear.

The IPF cost model presented herein would normally be used to estimate costs based on the mobilization requirements rather than peacetime requirements. This overstates the IPF requirements and costs for peacetime production, but satisfies the conditions dictated by the mobilization base plan.

The model is structured so that computer programing can provide for separate calculation of the estimated costs of initial tooling and test and measuring equipment, to the exclusion of IPE. This is predicated on the basis that, for a given ammunition program, the Government will not buy capital equipment but will incur costs for special tooling and gages unique to the ammunition being procurred.

TABLE III - 1 NONRECURRING INVESTMENT COST ELEMENTS

1. IPE, 20mm-30mm
   - a. Projectile (HEIT, APT, and TPT) and Link
   - b. Box
   - c. LAP
   - d. Cartridge Case
   - e. Fuze
2. Initial tooling, 20mm-30mm
   - a. Projectile (HEIT, APT, and TPT), Link, Box, and LAP
   - b. Cartridge Case

3. IPE over 30mm-60mm

a. Projectile (HEIT, APT, and TPT)
b. LAP
c. Cartridge case
d. Fuze

4. Initial tooling over 30mm-60mm

a. Projectile (HEIT, APT, and TPT) and LAP
b. Cartridge Case

1. IPE 20mm-30mm

The IPE (machine tools and processing equipment) required for the manufacture of a 20-30mm steel-case ammunition family is shown in Tables III-2 through III-8. The equipment lists were synthesized in a previous study, reference 51, by analyzing the manufacturing processes necessary to produce this ammunition. An adjustment factor of 1.12 was used to inflate equipment unit costs from FY-73 dollars to FY-74 dollars. It was developed from a detailed review of the production base support procurement requisition order numbers (PRONS) for FY-74 on ARMCOM projects. The price changes on the PRONS indicate a change of 12 percent through the fiscal year. In addition to the equipment costs obtained from Tables III-2 through III-8, the cost model selectively includes allowances for test and measuring equipment, transportation, installation, and layaway costs. The tables also include special initial tooling costs for each equipment item. Initial tooling required by the IPE was developed by analyzing the manufacturing processes and equipment requirements, and was inflated from FY-73 dollars to FY-74 dollars.

Tables III-2 through III-8 constitute matrices from which cost values and equipment capacities required for solution of the cost equations are selected. The notation used in the cost equations applies to each matrix. Since the cost of a fuze line is provided at the summary (total line) level, there is no matrix for fuzes. The explanations given below include the notation for initial tooling. The over 30-60mm sizes use the same notation as the 20-30mm group, but they also employ additional notation unique to the model for ammunition sizes over 30mm-60mm.

Subscripts

i — is a matrix row: a specific item of equipment and associated initial tooling

j — is a matrix column; it refers either to equipment unit cost, annual equipment capacity per shift, or average unit initial tooling cost.

k — is the specific matrix; e.g., when k=1, the HEIT Projectile matrix, Table III-2, is specified.

Symbols

C_k is the number of working shifts assumed in the estimate for the ammunition component identified by the value of k, where a shift is eight hours per day, five days per week (1-8-5). When one shift is assumed, C_k is given the value of 1; similarly, $C_k=2$ and $C_k=3$ for two and three shifts respectively, where the latter value is the maximum acceptable to the program.

Q_k is the annual production quantity of the ammunition component specified by the value of k in millions.

$X_{i,j,k}$ is the numerical value (cost or equipment capacity) located at the intersection of row i and column j of matrix k; e.g., $X_{3,2,1}$ provides the value 1.700 million rounds as the annual capacity per shift for the centerless grinder required to produce the HEIT projectile.

$N_{i,k}$ is the required quantity of the equipment item specified by row i of matrix k; e.g., $N_{3,1}$ represents the number of centerless grinders, that have an annual capacity of $C_1X_{3,2,1}$ rounds, that are required to produce Q_1 HEIT projectiles (See cost equations).

$Y_{i,k}$ is the total cost in thousands of dollars of the equipment item specified by row i of matrix k, or its associated initial tooling; it is a function of $N_{i,k}$ and $X_{i,j,k}$.

Y_k is the total cost in thousands of dollars of the equipment needed to meet Production requirements of the ammunition component specified by the value of K. It also includes the cost of test and measuring equipment.

T_k is the total cost in thousands of dollars of test and measuring equipment required for the component specified by the value of k; it is independent of the quantity specified by Q_k

Using the foregoing notation, the cost equations by component are as follows:

a. Projectile (HEIT, APT, and TPT) and Link (k=1,2,3, and 4, respectively)

$$N_{i,k} = \frac{Q_k}{C_kX_{i,2,k}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [1a1]$$

where: $N_{i,k}$ = the required equipment item quantity as previously defined, rounded to the next larger integer; e.g., if $Q_k \div C_kX_{i,2,k}$ = 2.005, then $N_{i,k}$ is rounded to 3.

Q_k = annual production-quantity requirement as previously defined Note: Q_1 (HEIT projectile), Q_2 (APT projectile), and Q_3 (TPT projectile) represent unique input variables; Q_4 (link)

is the sum of Q_1, Q_2, and Q_3 or is set equal to zero if link-production equipment is assumed to be in existence or is otherwise not required.

C_k = the assumed number of shifts per day.

$X_{i,2,k}$ = the annual capacity per shift of equipment item i in matrix k.

$$Y_{i,k} = N_{i,k}X_{i,1,k} \quad \text{[1a2]}$$

where: $Y_{i,k}$ = the total cost of equipment item i used to produce the component k.

$N_{i,k}$ = value from equation [1a1].

$X_{i,1,k}$ = unit cost of equipment item i used to produce the component k.

$$Y_k = \sum Y_{i,k}(1.155) + T_k \quad \text{[1a3]}$$

where: Y_k = the total cost of all equipment items necessary to meet production requirements of each projectile or link plus the cost of test and measuring equipment.

$Y_{i,k}$ = values from equation [1a2].

1.155 = 1.1(1.05), an additional 5-percent allowance for transportation and installation, and 10 percent for layaway costs.

Note: The transportation and installation allowances were provided by the US Army Production Equipment Agency. The layaway allowance was provided by the Industrial Management Division of the Procurement and Production Direcorate at ARMCOM. It consists of 6 percent for preservation and 4 percent for crating, handling, and transportation. If layaway is on the site, only the 6-percent factor is applicable; however, the 10-percent factor is used in the model to yield a conservative estimate based upon the assumption that on-site layaway versus plant clearance is not known at the time that the estimate is being made.

T_k = Total cost of test and measuring equipment, and is equal to 24.0 for k=1 and 2, 22.5 for k=3, and 26.9 for k=4.

b. Box (k=5)

$$N_{i,5} = \frac{1000Q_5}{C_5X_{i,2,5}} \quad \text{[1b1]}$$

where: $N_{i,5}$ = the required equipment item quantity rounded to the next larger integer.

$Q_5 = Q_1 \cdot Q_2 \cdot Q_3$, the annual box production-quantity requirement, expressed in millions of rounds. (See note, bottom of Table III-6); Q_5 is set equal to zero if box-production equipment and tooling are assumed to be in existence or is otherwise not required.

C_5 = the assumed number of shifts per day.

$X_{i,2,5}$ = the annual capacity per shift of equipment item i in matrix k where k = 5. This is expressed in millions of rounds.

Z = the number of rounds per box known or assumed for the estimate.

100 = the number of rounds per box assumed in establishing the matrix k=5.

$$Y_{i,5} = N_{i,5} X_{i,1,5} \quad \text{[1b2]}$$

where: $Y_{i,5}$ = the total cost of equipment item i used to produce ammunition boxes.

$N_{i,5}$ = the value from equation [1b1].

$X_{i,1,5}$ = the unit cost of equipment item i used to produce ammunition boxes.

$$Y_5 = \sum Y_{i,5}(1.155) + T_5 \quad \text{[1b3].}$$

where: Y_5 = the total cost of all equipment items necessary to meet ammunition box production requirements, plus the cost of test and measuring equipment.

$Y_{i,5}$ = the values from equation [1b2].

1.155 = 1.1(1.05), an additional 5-percent allowance for transportation and installation, and 10 percent for layaway costs.

T_5 = 10.5 for k=5, and is defined under equation [1a3].

c. LAP (k=6)

Equations [1a1] and [1a2] apply to the LAP equipment, with the subscript k=6, and $Q_6 = Q_1 + Q_2 + Q_3$. The total-cost summation equation for LAP equipment is as follows:

$$Y_6 = \sum Y_{i,6}(1.2705) + T_6 \quad \text{[1c3].}$$

where: Y_6 = the total cost of all items of equipment required to LAP the ammunition components, plus the cost of test and measuring equipment.

$Y_{i,6}$ = the values from equation [1a2] applied to the LAP matrix, Table III-7(k=6).

1.2705 = 1.1(1.155), a 10-percent allowance for miscellaneous material handling equipment applied in addition to the allowances previously defined.

T_6 = 38.5 for k=6 and is defined under equation [1a3].

d. Cartridge Case (k=7)

$$N_{i,7} = \frac{Q_7}{C_7 X_{i,3,7}} \quad \text{. . . . . [1d1].}$$

where: $N_{i,7}$ = the required equipment item quantity rounded to the next larger integer.

$Q_7 = Q_1+Q_2+Q_3 = Q_6$, the annual production quantity requirement.

C_7 = the assumed number of shifts per day.

$X_{i,3,7}$ = the annual capacity per shift of equipment item i used to produce cartridge cases.

Alternative choices of equation [1d2] are based on a variation in the number of drawing operations and the press tonnages required for the blanking and drawing operations, depending on the ratio of length to diameter of the cartridge case being estimated. The former variation is accounted for by the addition of equipment items 25 and 26 (4th draw and 4th draw trim) in Table III-8; whereas the latter variation is accounted for by variations in affected press tonnages and the addition of a second column of equipment unit costs (j=2) to Table III-8 to accommodate the higher tonnages. Under conditions (1), (2) and (3), below, L is the total length of the case in inches, and D is the projectile diameter in millimeters.

(1) $L \leq 3.5$ in., $D \leq 30$mm, i = 1, 2, ..., 24

$$Y_{i,7} = N_{i,7} X_{i,1,7} \quad \text{. . . . . [1d2}_1\text{].}$$

where: $Y_{i,7}$ = the total cost of equipment item i used to produce cartridge cases.

$N_{i,7}$ = The values from equation [1d1].

$X_{i,1,7}$ = the unit cost of equipment item i used to produce cartridge cases.

(2) $L > 3.5$ in., $D = 20$mm, $i = 1, 2, \ldots, 26$

$$Y_{i,7} = N_{i,1,7} X_{i,1,7} \quad \ldots \quad [1d22].$$

where all factors are as defined in paragraph (1) above.

(3) $L > 3.5$ in., $20\text{mm} < D \leq 30\text{mm}$, $i = 1, 2, \ldots, 26$.

$$Y_{i,7} = N_{i,7} X_{i,2,7} \quad \ldots \quad [1d23].$$

where all factors are as defined in paragraph (1) above.

(4) Summation equation for conditions (1), (2), (3):

$$Y_7 = \sum Y_{i,7}(1.155) + T_7 \quad \ldots \quad [1d3].$$

where: Y_7 = the total cost of all items of equipment necessary to meet cartridge case production requirements, plus the cost of test and measuring equipment.

$Y_{i,7}$ = the values from appropriate conditional equation [1d2].

1.155 = 1.1(1.05), an additional 5-percent allowance for transportation and installation, and 10 percent for layaway costs.

T_7 = 54.5 for k=7, and is defined under equation [1a3].

e. <u>Fuze Line</u>

$$N = \frac{Q}{1.2C} \quad \ldots \quad [1e1].$$

where: N = the number of fuze lines required to meet annual production quantity requirements, rounded to the next larger integer

$Q = Q_1$, the annual production quantity requirement.

C = the assumed number of shifts per day.

1.2 = a constant annual production capacity per fuze line per shift expressed in millions.

$$Y = N(1,786)\ (1.10) + T \quad \ldots \quad [1e2].$$

where: Y = the total cost of the fuze line(s) required to meet fuze-production requirements, including layaway cost, plus the cost of test and measuring equipment.

N = the value from equation [1e1].

1,786 = the average unit cost per line, excluding layaway cost, expressed in thousands.

1.10 = an additional 10-percent allowance for layaway cost.

T = 178.6 for fuzes as defined under equation [1a3].

2. Initial Tooling, 20mm-30mm

This cost element covers the special initial tooling required for the IPE items shown in Tables III-2 through III-8 covering projectiles, links, boxes, LAP, and cartridge cases. The number of sets of initial tooling required for each equipment item i of each matrix is the same as the corresponding equipment item i quantity previously calculated using the IPE cost equations in sections 1a through 1d. (No tooling is required for fuzes.) This quantity is expressed for IPE quantities as $N_{i,k}$. Given the previously calculated values of $N_{i,k}$, the resulting initial tooling cost equations are:

a. Projectile (HEIT, APT, and TPT), Link, Box, and LAP (k=1, 2, 3, 4, 5, and 6, respectively)

$$Y_{i,k} = N_{i,k}X_{i,j,k} \quad \text{. . . . . [2a2].}$$

where: $Y_{i,k}$ = the total cost of the initial tooling required for equipment item i of matrix k

$N_{i,k}$ = the value from equation [1a1] or [1b1], as applicable for the value of k for the component being estimated

$X_{i,j,k}$ = the average unit tooling cost for equipment item i of matrix k, where the value of subscript j = $N_{i,k}$ +2

$$Y_k = \Sigma Y_{i,k} \quad \text{. . . . . [2a3].}$$

where: Y_k = the total cost of all initial tooling required to meet production requirements of the ammunition component specified by the value of k.

$Y_{i,k}$ = the values from equation [2a2].

b. Cartridge case (k=7)

The conditional cost equations for cartridge cases are as follows (same length and diameter categories as those for IPE, sections 1d (1) through 1d (3):

(1) $L \leq 3.5$ in., $D < 30$mm, i = 1, 2, ..., 24

$$Y_{i,7} = N_{i,7}X_{i,j,7} \ldots\ldots\ldots\ldots \text{[2b2.1]}.$$

where: $Y_{i,7}$ = total cost of the initial tooling required for cartridge case equipment item i.

$N_{i,7}$ = the value from equation [1d1].

$X_{i,j,7}$ = the average unit tooling cost for cartridge case equipment item i, where the value of subscript $j = N_{i,7}+3$

(2) $L > 3.5$ in., $D = 20$mm, $i = 1, 2, \ldots, 26$

$$Y_{i,7} = N_{i,7}X_{i,j,7} \ldots\ldots\ldots\ldots \text{[2b22]}.$$

where each variable is as defined in equation [2b21].

(3) $L > 3.5$ in., $20\text{mm} < D \leq 30\text{mm}$, $i = 1, 2, \ldots, 26$

$$Y_{i,7} = 2N_{i,7}X_{i,j,7} \ldots\ldots\ldots\ldots \text{[2b23]}.$$

where each variable is as defined in equation [2b21]; and factor 2 provides for doubling the initial tooling matrix value, based on the engineering judgment of Lake City Ammunition Plant personnel, to account for the higher cost of the heavier press tooling. (See section 1d).

(4) Summation equation for conditions (1), (2), or (3):

$$Y_7 = \sum Y_{i,7} \ldots\ldots\ldots\ldots \text{[2b3]}.$$

where: Y_7 = the total cost of all initial tooling required to meet cartridge case production requirements.

$Y_{i,7}$ = the values from appropriate conditional equation [2b2].

3. IPE over 30mm-60mm

The IPE required for the manufacture of an over 30mm through 60mm steel-case ammunition family is shown in Tables III-9 through III-13. The equipment lists were developed from a detailed analysis of the manufacturing processes necessary to produce the 57mm family provided in references 1 through 7. Appropriate modifications to these processes were made, so that the conventionally cased ammunition, as opposed to the recoilless-rifle family, is reflected in the equipment lists. In addition to the equipment costs obtained from Tables III-9 through III-13, the cost model selectively includes allowances in the cost equations for test and measuring equipment, transportation, installation, and layaway costs. The tables also include special initial tooling costs per equipment item. Required initial tooling was developed and costs were estimated from the detailed information presented in references 1 through 7.

Tables III-9 through III-13 constitute matrices from which the cost model selects cost values and equipment capacities required for the solution of the cost equations. Since these matrices are based on 57mm ammunition, the cost model selectively applies dimensional adjustments in the cost equations for size variations affecting equipment capacities. The notation used in the cost equations applies uniformly to each matrix and is identical to that presented previously except for the following additions:

Subscripts

c identifies cartridge case.

p identifies projectile.

Symbols

D is the projectile diameter of the ammunition family for which IPE is being estimated. Expressed in millimeters, this value ranges from over 30mm through 60mm.

L_p is the projectile length in inches.

L_c is the cartridge case length in inches.

n is the upper value of i representing the last item of equipment within the range of i values for a specific matrix k for which a dimensional adjustment to equipment capacity per shift is required because of projectile length and diameter. The values of i are taken in sequence starting with $i=1$.

m is the upper value of i representing the last item of equipment within the range of i values for a specific matrix k for which a dimensional adjustment to equipment capacity per shift is required because of the projectile diameter only. The values of i are taken in sequence starting with $i = n + 1$.

q is the upper value of i representing the last item of equipment within the range of i values for a specific matrix k for which a dimensional adjustment to equipment capacity per shift is not required. The values of i are taken in sequence starting with $i = m + 1$.

$NA_{i,k}$ is the required quantity of the equipment item specified by row i in matrix k, where i ranges in value from 1 through n.

$NB_{i,k}$ is the required quantity of the equipment item specified by row i in matrix k, where i ranges in value from n+1 through m.

$NC_{i,k}$ is the required quantity of the equipment item specified by row i in matrix k, where i ranges in value from m+1 through q.

$YA_{i,k}$ is the total cost in thousands of dollars of the equipment item specified by row i in matrix k, where the value of i ranges from 1 through n; it is a function of $NA_{i,k}$ and $X_{i,j,k}$.

$YB_{i,k}$ is the same as $YA_{i,k}$, except that the value of i ranges from n+1 through m.

$YC_{i,k}$ is the same as $YA_{i,k}$, except that the value of i ranges from m+1 through q.

The cost equations by component, using the foregoing notation, are as follows:

a. <u>Projectile (HET, APT, and TPT)</u> (k = 8, 9, and 10, respectively).

$$NA_{i,k} = \frac{DL_pQ_k}{480\ C_kX_{i,2,k}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{[3a1]}.$$

where: $NA_{i,k}$ = the required equipment item quantity as previously defined, rounded to the next larger integer; e.g., if $DL_pQ_k \div 480\ C_kX_{i,2,k} = 2.005$, then $NA_{i,k}$ is rounded to 3.

Note: i ranges from 1 through n.

D = the projectile diameter.

L_p = the projectile length.

Q_k = the annual production quantity requirement.

480 = 60mm times 8 inches, which represents the 60mm-projectile diameter and an assumed 8-inch maximum projectile length.

Note: To express the upper model limits in the equipment quantity equation, a projectile diameter of 60mm is used as an estimating

base rather than 57mm. True variation in required equipment quantity, caused by capacity variation with projectile diameter, is a step function. A quantity variation would not be expected between 57mm and 60mm.

C_k is the assumed number of shifts per day.

$X_{i,2,k}$ is the annual capacity per shift of equipment item i of matrix k.

$$NB_{i,k} = \frac{DQ_k}{60\ C_k X_{i,2,k}} \quad \ldots\ldots\ldots\ldots\ldots [3a2].$$

where: $NB_{i,k}$ = the required equipment item quantity rounded to the next larger integer.

Note: i ranges in value from n+1 through m.

60 = the upper model limit on projectile diameter.
All other factors are as defined for equation [3a1].

$$YA_{i,k} = NA_{i,k} X_{i,1,k} \quad \ldots\ldots\ldots\ldots\ldots [3a3].$$

where: $YA_{i,k}$ = the total cost of equipment item i.

Note: i ranges in value from 1 through n.

$NA_{i,k}$ = the value from equation [3a1].

$X_{i,1,k}$ = the unit cost of equipment item i.

$$YB_{i,k} = NB_{i,k} X_{i,1,k} \quad \ldots\ldots\ldots\ldots\ldots [3a4].$$

where: $YB_{i,k}$ = the total cost of equipment item i.

Note: i ranges in value from n+1 through m.

$NB_{i,k}$ = the value from equation [3a2].

$X_{i,1,k}$ = the unit cost of equipment item i.

$$Y_k = [\sum_{i=1}^{n} YA_{i,k} + \sum_{i=n+1}^{m} YB_{i,k}]\ 1.155 + T_k \quad \ldots\ldots\ldots [3a5].$$

where: Y_k = the total cost of all items of equipment necessary to meet the production requirement of each projectile plus the cost of test and measuring equipment.

$YA_{i,k}$ = the values from equation [3a3].

$YB_{i,k}$ = the value from equation [3a4].

n = the upper value of i, as previously defined.

m = the upper value of i, as previously defined.

1.155 = 1.1(1.05), an additional 5-percent allowance for transportation and installation, and 10 percent for layaway costs.

T_k = the total cost of test and measuring equipment.

Note: n, m, and T_k assume the following values, dependent upon the value of k:

k	n	m	T_k
8	6	14	45.2
9	12	15	55.9
10	5	12	48.0

b. LAP (k=11)

Equations [3a1], [3a2], [3a3], and [3a4] apply to the LAP equipment, with the subscript k = 11, and $Q_k = Q_{11} = Q_8+Q_9+Q_{10}$. The following equations also apply:

$$NC_{i,11} = \frac{Q_{11}}{C_k X_{i,2,11}} \qquad [3b5].$$

where: $NC_{i,11}$ = the required equipment item quantity as previously defined, rounded to the next larger integer.

Note: i ranges in value from m+1 through q.
All other factors are as defined in equation [3a1].

$$YC_{i,11} = NC_{i,11} X_{i,1,11} \qquad [3b6].$$

where: $YC_{i,11}$ = the total cost of equipment item i as previously defined. Note: i ranges in value from m+1 through q.

$NC_{i,11}$ = the value from equation [3b5].

$X_{i,1,11}$ = as defined in equation [3a3].

$$Y_{11} = [\sum_{i=1}^{n} YA_{i,11} + \sum_{i=n+1}^{m} YB_{i,11} + \sum_{i=m+1}^{q} YC_{i,11}]1.2705+T_{11} \quad . \; . \; . \; . \; [3b7].$$

where: Y_{11} = the total cost of all items of equipment required to load, assemble, and pack the ammunition components, plus the cost of test and measuring equipment.

$YA_{i,11}$ = values from equation [3a3] with subscript k=11.

$YB_{i,11}$ = values from equation [3a4] with subscript k=11.

$YC_{i,11}$ = values from equation [3b6].

n = 8 for k=11 and is as previously defined.

m = 11 for k=11 and is as previously defined.

q = 15 for k=11 and is as previously defined.

1.2705 = 1.1(1.155), a 10-percent allowance for miscellaneous material handling equipment applied in addition to the allowance previously defined.

T_{11} = 158.0, the total cost of test and measuring equipment.

c. Cartridge Case (k=12)

$$NA_{i,12} = \frac{DL_c Q_{12}}{720\ C_{12} X_{i,2,12}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; [3c1].$$

where: $NA_{i,12}$ = the required equipment item quantity as previously defined, rounded to the next larger integer.

Note: i ranges in value from 1 through n.

D = the projectile diameter.

L_c = the cartridge case length.

$Q_{12} = Q_8+Q_9+Q_{10}=Q_{11}$, the annual production quantity requirement.

720 = 60 times 12 inches, which represents the 60mm-projectile diameter and the 12-inch length of the 57mm cartridge case, the upper model limits. (See equation [3a1] for note relating to the 60mm upper limit).

C_{12} = the assumed number of shifts per day.

$X_{i,2,12}$ = the annual capactiy per shift of equipment item i used to produce cartridge cases.

Equation [3a2] also applies to the cartridge case equipment, when k=12, n=18, m=27, and Q_{12} is as defined for equation [3c1]. The following equation also applies:

$$NC_{i,12} = \frac{Q_{12}}{C_{12}X_{i,2,12}} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad [3c3].$$

where: $NC_{i,12}$ = the required equipment-item quantity rounded to the next larger integer.

Note: i ranges in value from m+1 through q.

All other factors are as defined for equation [3c1].

$$YA_{i,12} = NA_{i,12}X_{i,1,12} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad [3c4].$$

where all factors are as defined for equations [3a3] and [3c1], and when k=12 and n=18.

Equation [3a4] also applies to the cartridge case equipment, when k=12, n=18, m=27, and Q_{12} is as defined for equation [3c1]. The following equation also applies:

$$YC_{i,12} = NC_{i,12}X_{i,1,12} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad [3c6].$$

where: $YC_{i,12}$ = the total cost of equipment item i as previously defined.

Note: i ranges in value from m+1 through q.

$NC_{i,12}$ = the value from equation [3c3].

$X_{i,1,12}$ = the unit-equipment cost.

$$Y_{12} = [\sum_{i=1}^{n} YA_{i,12} + \sum_{i=n+1}^{m} YB_{i,12} + \sum_{i=n+1}^{q} YC_{i,12}]1.155 + T_{12} \quad . \ . \ . \ . \quad [3c7].$$

where: Y_{12} = the total cost of all items of equipment required to meet cartridge-case production requirements, plus the cost of test and measuring equipment.

$YA_{i,12}$ = the values from equation [3c4].

$YB_{i,12}$ = the values from equation [3a4] with subscript k=12.

$YC_{i,12}$ = the values from equation [3c6].

n = 18 for k=12, and is as previously defined.

m = 27 for k=12, and is as previously defined.

q = 31 for k=12, and is as previously defined.

1.155 = 1.1(1.05), an additional 5-percent allowance for transportation and installation, and 10 percent for layaway costs.

T_{12} = 150.0, the total cost of test and measuring equipment.

d. Fuze Line

Based on a discussion with personnel from the Mobilization Engineering Division at Frankford Arsenal, the cost estimates and production rates for the XM714 fuze lines can be used for the full 20mm through 60mm range of ammunition. Therefore, equations [1e1] and [1e2] of section IIIB1e are to be used here to calculate the total cost of the fuze line(s) required to meet fuze production requirements, including layaway cost and test and measuring equipment.

4. Initial Tooling, over 30mm-60mm

This cost element covers the special initial tooling required for the IPE items shown in Tables III-9 through III-13 for projectiles, LAP, and cartridge cases. No tooling is required for fuzes. The number of initial tooling sets required for each equipment item i in each matrix k is the same as the corresponding equipment item i quantity previously calculated using the equipment quantity equations in sections 3a through 3c. This quantity is expressed for IPE as $N_{i,k}$. Given the previously calculated values of $N_{i,k}$, the resulting initial tooling cost equations are:

a. Projectile (HET, APT, and TPT) and LAP (k=8,9,10, and 11, respectively).

$$YA_{i,k} = NA_{i,k}X_{i,j,k} \quad \ldots\ldots\ldots\ldots\ldots \quad [4a2].$$

where: $YA_{i,k}$ = the total cost of the initial tooling required for equipment item i of matrix k.

Note: i ranges in value from 1 through n.

$NA_{i,k}$ = the values from equation [3a1] for the ammunition component specified by the value of k where k=8,9,10, or 11, and the appropriate value of i.

$X_{i,j,k}$ = average unit initial tooling cost for equipment item i of matrix k, where the value of subscript j = $NA_{i,k}$ + 2

$$YB_{i,k} = NB_{i,k}X_{i,j,k} \quad \ldots\ldots\ldots\ldots\ldots \quad [4a4].$$

where: $YB_{i,k}$ = the total cost of the initial tooling required for equipment item i of matrix k.

Note: i ranges in value from n+1 through m.

$NB_{i,k}$ = values from equation [3a2] for the ammunition component specified by the value of k where k = 8,9,10, or 11, and for the appropriate value of i.

$X_{i,j,k}$ = as defined in equation [4a2] where the value of subscript $j = NB_{i,k} + 2$

$$YC_{i,k} = NC_{i,k}X_{i,j,k} \quad \text{[4a6].}$$

where: $YC_{i,k}$ = the total cost of the initial tooling required for equipment item i in matrix k. See note following equation [4a7].

Note: i ranges in value from m+1 through q.

$NC_{i,k}$ = values from equation [3b5] for the ammunition component specified by the value of k=11 and the appropriate value of i.

$X_{i,j,k}$ = as defined in equation [4a2] where the value of subscript $j = NC_{i,k} + 2$

$$Y_k = \sum_{i=1}^{n} YA_{i,k} + \sum_{i=n+1}^{m} YB_{i,k} + \sum_{i=m+1}^{q} YC_{i,k} \quad \text{[4a7].}$$

where: Y_k = the total cost of all initial tooling necessary to meet production requirements of the ammunition component specified by the value of k.

$YA_{i,k}$ = the value from equation [4a2].

$YB_{i,k}$ = the value from equation [4a4].

$YC_{i,k}$ = the value from equation [4a6].

n = the upper value of i as defined in equation [3a5].

m = the upper value of i as defined in equation [3a5].

q = the upper value of i as defined in equation [3b7].

Note 1: n, m, and q assume the following values dependent upon the value of k:

k	n	m	q
8	6	14	-
9	12	15	-
10	5	12	-
11	8	11	15

Note 2: The summation of $YC_{i,k}$ only applies to equation [4a7] when k=11.

b. Cartridge Case (k=12)

Equations [3c1], [3c4], [3a2], [3a4], [3c3], and [3c6] apply to the initial tooling necessary to meet production requirements for cartridge cases, with subscript k=12, and $Q_{12}=Q_8+Q_9+Q_{10}=Q_{11}$. The total cost summation equation for cartridge case initial tooling is:

$$Y_k = \sum_{i=1}^{n} YA_{i,k} + \sum_{i=n+1}^{m} YB_{i,k} + \sum_{i=m+1}^{q} YC_{i,k} \quad \text{[4b7].}$$

where: Y_k = the total cost of all initial tooling necessary to meet production requirements for cartridge cases where k=12 and where all other factors are as defined in equation [3c7].

TABLE III - 2 HEIT PROJECTILE (k=1)

Matrix Values $X_{i,j,k}$

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $X_{i,k}$ = 1,2,3.....∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12)	(j=13)	(j=14)	(j=15→∞)
1	Auto Screw Machine	[illegible]	.413	[illegible]	4.630	4.630	[illegible]	4.630	2.936	2.936	2.936	2.444	2.444	2.444	2.354	→
2	Secondary Open Chucker	66[illegible]	[illegible]	2.29	1.650	[illegible]	[illegible]	[illegible]								→
3	Centerless Grinders	[illegible]	[illegible]	0												→
4	35-Ton Hydraulic Press	[illegible]	[illegible]	2.20	1.650											→
5	[illegible]-Ton Hydraulic Press	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]									→
6	Press, Sand Dressing	[illegible]	[illegible]	[illegible]	[illegible]											→
7	Phosphate Coating Unit	[illegible]	[illegible]	0												→
8	Magnetic Inspect Mach	[illegible]	[illegible]	0												→
9	Wash, Rinse & Dry Unit	[illegible]	[illegible]	0												→
10	Marking Machine	[illegible]	[illegible]	0												→
11	Painting Machine	[illegible]	[illegible]	0												→

TABLE III - 3 APT PROJECTILE (k=2)

Matrix Values $X_{i,j,k}$

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $X_{i,k}$=1,2,3,....∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9→∞)
1	Auto Screw Machine	$78.460	.413	7.70	7.700	6.767	6.400	6.400	6.034	→
2	Single Spindle Screw Machine	22.420	.825	4.40	3.300	2.934				→
3	Centerless Grinders	36.120	2.250	0						→
4	Tocco Induc Heat Unit	43.590	2.250	0						→
5	Turret Lathe	28.665	1.125	1.10	.825					→
6	Press, 15 Ton	7.470	1.125	2.20	1.650					→
7	Degreaser	22.420	2.250	0						→
8	Magnetic Part Insp Machine	33.630	2.250	0						→
9	Phosphate Coating Unit	70.990	2.250	0						→
10	Painting Machine	43.590	2.250	0						→

TABLE III - 4 TPT PROJECTILE (k=3)

i	Equipment Item	Equipment Unit Cost in Thousands (j=1)	Equipment Capacity Shift in Millions (j=2)	Matrix Values $X_{i,j,k}$: Ave Unit Tooling Cost ($ in thousands) as $X_{i,k}$=1,2,3,....,∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9→∞)
1	Auto Screw Machine	[illegible]	.542	[illegible]	1.399	1.330	1.399	1.399	2.567	→
2	Auto Screw Machine	[illegible]	.653	3.96	[illegible]	2.429	2.429	1.696		→
3	Centerless Grinders	[illegible]	1.625	[illegible]						→
4	Hydraulic Press ([illegible] ton)	[illegible]	1.625	[illegible]	1.653					→
5	Press, Band Swaging	[illegible]	1.625	[illegible]	1.333					→
6	Phosphate Coating Unit	[illegible]	1.625	[illegible]						→
7	Magnetic Part Insp Machine	[illegible]	3.25	[illegible]						→
8	Wash, Rinse & Dry Unit	[illegible]	3.25	[illegible]						→
9	Marking Machine	[illegible]	3.25	[illegible]						→
10	Painting Machine	[illegible]	3.25	[illegible]						→

TABLE III - 5 LINK (k=4)

i	Equipment Item	Equipment Unit Cost in Thousands (j=1)	Equipment Capacity Shift in Millions (j=2)	Matrix Values $X_{i,j,k}$: Ave Unit Tooling Cost ($ in thousands) as $X_{i,k}$=1,2,3,....,∞ (j=3)	(j=4)	(j=5)	(j=6)	(j=7→∞)
1	15?-Ton Blank & Form Press	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		→
2	#35 Mult. Slide Press	[illegible]	[illegible]	[illegible]	35.754	[illegible]		→
3	Secondary Opr. ([illegible]) Press	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.376	→
4	Heat Treat Furnace	[illegible]	[illegible]	[illegible]				→
5	Vibratory Deburring Machines	[illegible]	[illegible]	[illegible]				→
6	Assembly Machine	[illegible]	[illegible]	[illegible]				→
7	Ranschoff Wash & Dry	[illegible]	[illegible]	[illegible]				→
8	Vapor Degreaser	[illegible]	[illegible]	[illegible]				→
9	Phosphate Coating [illegible]	[illegible]	[illegible]	[illegible]				→

TABLE III - 6 BOX (k=5)

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10→∞)
1	Punch Press 135-150 Ton	$28.645	6.7	60.50	60.500	60.500	52.255	51.705	51.330	→	→
2	Punch Press 60-70 Ton	14.945	6.2	8.80	8.800	8.800	8.388	8.381	8.342	8.329	→
3	Punch Press 20-30 Ton	7.470	8.3	4.40	4.400	4.034	3.988	3.960	→	→	→
4	Press Brake 50-60 Ton	14.945	8.3	8.80	8.800	8.435	8.388	8.361	→	→	→
5	Seam Welders	17.440	5.0	0	→	→	→	→	→	→	→
6	Spot Welders	11.215	2.8	0	→	→	→	→	→	→	→

NOTE: $X_{i,2,k}$ (the production equipment capacity for ammunition boxes) is expressed in rounds of ammunition instead of boxes, i.e., 67,000 boxes times 100 rounds per [illegible] rounds

TABLE III - 7 LAP (k=6)

i	Equipment Item	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Avg Unit Tooling Cost ($ in Thousands) as $N_{i,k}=1,2,3,\ldots,\infty$ (j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12)	(j=13)	(j=14→∞)
1	Blending Units	$ 9.960	4.200	0	→	→	→	→	→	→	→	→	→	→	→
2	Pelletizers	21.170	4.200	5.50	4.400	→	→	→	→	→	→	→	→	→	→
3	Charging Machine	191.800	1.680	16.50	16.500	16.500	16.500	16.500	→	→	→	→	→	→	→
4	Straight Line Loaders	78.460	1.680	8.80	8.800	8.800	8.800	4.400	→	→	→	→	→	→	→
5	Auto Fuze Assemblers	43.590	.764	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	→
6	Cage & Weight	78.460	4.200	13.20	11.000	→	→	→	→	→	→	→	→	→	→
7	Can Sealer	9.960	2.800	0	→	→	→	→	→	→	→	→	→	→	→
8	Marking Machine	14.945	4.200	0	→	→	→	→	→	→	→	→	→	→	→

TABLE III - 8 CARTRIDGE CASE (h=7)

	Equipment Item					Matrix Values $X_{i,j,h}$								
			Equipment Unit Cost In Thousands	Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in thousands) on $Y_{i,h}$=1,2,3, ..., ∞								
i	Operation	Machine	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8)	(j=9)	(j=10)	(j=11)	(j=12 → ∞)
1	Blank	100T(j=1) 200T(j=2)	$ 62.270	124.540	5.050	11.00	6.821							→
2	Wash/Dry	42" Spiral 4 Stage	31.140	31.140	5.050	0								→
3	Anneal	3K #/hr. 1400°	467.000	467.000	10.100	0								→
4	Descal & Coat	60" Spiral 9 Stage	137.000	137.000	10.100	0								→
5	Coin Cup	400T	249.090	249.090	3.367	2.64	2.090	1.996						→
6	1st Draw	150T(j=1)/200T(j=2)	93.410	124.540	3.367	0.88	.715	.660						→
7	2d Draw	100T(j=1)/200T(j=2)	62.270	124.540	3.367	0.88	.715	.660						→
8	2d Draw Trim	Rotary	19.930	19.930	2.020	0.55	.550	.404	.385	.374				→
9	3d Draw	100T(j=1)/200T(j=2)	62.270	124.540	3.367	0.88	.715	.660						→
10	3d Draw Trim	Rotary	21.170	21.170	2.020	0.55	.550	.404	.385	.374				→
11	Indent & Head	200T	124.540	124.540	2.020	0.99	.990	.440	[illegible]	.396				→
12	Head Turn	Screw Mach 8 Spdle	92.160	92.160	1.283	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	→
13	Pierce Flash Hole	5T Horizontal	57.290	57.290	3.367	0.55	.440	.404						→
14	Pretaper Trim	Rotary	21.170	21.170	2.525	0.55	.550	.404	.385					→
15	Taper	65T Horizontal	74.730	74.730	3.367	1.65	1.155	.990						→
16	Preharden Wash	42" 4 Stage	32.380	32.380	10.100	0								→
17	Harden & Quench	1800° Tube Type	249.090	249.090	5.050	0								→
18	Temper	800° Belt	70.990	70.990	5.050	0								→
19	Base Anneal	50 KW Ind	186.820	186.820	5.050	0								→
20	Mouth Anneal	50 KW Ind	118.320	118.320	5.050	0								→
21	Final Trim	Multiple Shimmy Trim	54.800	54.800	3.367	0.55	.440	.406						→
22	Rinse & Dry	42" 2 Stage	26.150	26.150	10.100	0								→
23	Mouth Size	20T	13.700	13.700	3.367	2.20	1.650	1.466						→
24	Coating System	Lacquer, Varnish, or Phosph	286.450	286.450	5.050	0								→
25	4th Draw	150T(j=1)/200T(j=2)	[illegible]	124.540	3.367	0.88	.715	.660						→
26	4th Draw Trim	Rotary	21.170	21.170	2.020	0.55	.550	.404	.385	.396				→

TABLE III - 9 HE-T PROJECTILE (k=8)

	Equipment Item		Matrix Values $X_{i,j,k}$							
			Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$ = 1,2,3,....m					
i	Operation	Machine	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6)	(j=7)	(j=8-m)
1	Form & Drill	6 Spindle Bar Machine	$106.6	.118	8.000	8.000	8.000	1.000 →	→	→
2	Broach Base	20T Press Hyd	89.9	.422	28.200	20.350	17.750 →	→	→	→
3	Blank Cover	#2 1/2 OBI Press	4.2	1.267	1.400	1.000	.850 →	→	→	→
4	Bonderize	Tanks	35.0	.591	12.000 →	→	→	→	→	→
5	Paint	Paint Machine	50.0	.368	0 →	→	→	→	→	→
6	Carton	Carton Stitcher	2.0	.422	0 →	→	→	→	→	→
7	Tracer Hole	B & S Lathe	36.4	.156	1.000	1.000	1.000	.400 →	→	→
8	Cold Nose	75T Press Hyd	106.3	.422	6.000	4.375	3.825 →	→	→	→
9	Size	Grinder	36.4	.161	5.600 →	→	→	→	→	→
10	Bore & Chamfer	4 Spindle Chucker	117.4	.231	9.600	9.600	9.600	6.275 →	→	→
11	Tap for Fuze	Tapping Machine	17.3	.127	.600 →	→	→	→	→	→
12	Mark	Stamping Machine	7.4	1.267	2.000	1.675	1.285 →	→	→	→
13	Weld Cover	30KVA Welder	3.5	.338	.600 →	→	→	→	→	→
14	Remove Teat	5T Ben. Press	2.0	1.200	.450	.300 →	→	→	→	→

TABLE III - 10 AP-T PROJECTILE (k=9)

	Equipment Item		Matrix Values $X_{i,j,k}$					
			Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in thousands) as $N_{i,k}$ = 1,2,3,....m			
i	Operation	Machine	(j=1)	(j=2)	(j=3)	(j=4)	(j=5)	(j=6-m)
1	Form & Cutoff	Bar Machine	$106.6	.027	4.500	4.500	2.500 →	→
2	Broach	60T Press Hyd	104.3	.422	6.000	4.375	3.825 →	→
3	Clean	Auto Wash Conveyor	8.0	.139	0 →	→	→	→
4	Heat Treat	100KW Tocco Induction	135.6	.192	3.600 →	→	→	→
5	Bonderize	Tanks	35.0	.591	1.800 →	→	→	→
6	Blank	50T Press	59.0	1.267	2.000	1.800	1.600 →	→
7	Cup & Draw	60T Press Hyd	95.0	.453	4.800	4.350	4.150 →	→
8	Trim	25T OBI Press	3.2	.453	1.800	1.400	1.600 →	→
9	Wash	Tanks	15.0	.653	1.800 →	→	→	→
10	Paint	Paint Equipment	190.0	.368	3.600 →	→	→	→
11	Assemble	Press & Cinch Machine	2.0	1.326	3.400 →	→	→	→
12	Carton	Carton Stitcher	2.0	.422	0 →	→	→	→
13	Tracer Hole	Turret Lathe	36.4	.158	3.000 →	→	→	→
14	Mark	25T OBI Press	3.2	.653	1.300	.900	.750 →	→
15	Size	Grinder	36.4	.158	3.600 →	→	→	→

TABLE III - 11 TP-T PROJECTILE (k=10)

i	Equipment Item: Operation	Equipment Item: Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Matrix Values $X_{i,j,k}$: Ave Unit Tooling Cost ($ in thousands) as $X_{i,k}$ = 1,2,3,....,m (j=3)	(j=4)	(j=5)	(j=6)	(j=7→m)
1	Form & Drill	6 Spindle Bar Machine	$130.6	.318	8.000	8.000	8.000	3.000	→
2	Broach Band	200T Press Hyd	89.9	.422	28.200	20.35	17.250	→	→
3	[illegible]	Tanks	35.0	.591	12.000	→	→	→	→
4	Paint	Paint Machine	57.5	.348	0	→	→	→	→
5	Carton	Carton Stitcher	[illegible]	.422	0	→	→	→	→
6	Remove Teat	5T Bench Press	[illegible]	1.200	.450	.300	→	→	→
7	Cold Nose	250T Press Hyd	106.3	.422	6.000	4.375	3.825	→	→
8	Size	Grinder	38.4	.261	5.600	→	→	→	→
9	Bore & Chamfer	4 Spindle Chucker	117.4	.231	9.600	9.600	9.600	4.275	→
10	Tap for Fuze	Tapping Machine	17.3	.129	.600	→	→	→	→
11	Mark	Stamping Machine	7.6	1.267	2.000	1.475	1.285	→	→
12	Tracer Hole	B & S Lathe	36.4	.156	1.700	1.000	1.000	.433	→

TABLE III - 12 LAP (k=11)

i	Equipment Item: Operation	Equipment Item: Machine	Equipment Unit Cost In Thousands (j=1)	Equipment Capacity/Shift In Millions (j=2)	Matrix Values $X_{i,j,k}$: Ave Unit Tooling Cost ($ in thousands) as $X_{i,k}$ = 1,2,3,....m (j=3)	(j=4)	(j=5)	(j=6→m)
1	Assem Adapters & Consolidate	Hyd Press & Turntable	[illegible]	1.536	33.500	30.500	22.000	→
2	Tracer Assem	Tracer Loader	[illegible]	.512	1.250	→	→	→
3	Mix & Heat	Mix, Screen & Heat [illegible]	[illegible]	[illegible]	0	→	→	→
4	Assem Adapters & Fill	TNT Kettle	[illegible]	1.536	180.000	180.000	130.000	→
5	Probe	Auto Hot Probe [illegible]	[illegible]	.816	1.400	→	→	→
6	Assem & Clinch Primer	Primer Press	13.2	.512	1.200	→	→	→
7	Fill Case	Conveyor & Auto [illegible]	11.6	1.536	0	→	→	→
8	Assem & Crimp Projectile	Crimp Case & Pr[illegible]	[illegible]	1.024	1.400	→	→	→
9	Mark Projectile	Stamping Machine	[illegible]	1.536	2.000	→	→	→
10	Seat Fuze	Fuze Seating Machine	[illegible]	.626	1.500	→	→	→
11	Pellet Assem	Pellet Machine	[illegible]	1.536	2.000	→	→	→
12	Gage & Weigh	Shadow Graph	[illegible]	.768	0	→	→	→
13	Face Cavity	Air Drills	[illegible]	.816	1.600	→	→	→
14	Weigh	Weighing Scale	[illegible]	.768	0	→	→	→
15	Mark, Seal & [illegible]	Case Mark	13.2	1.536	0	→	→	→

TABLE III - 13 CARTRIDGE CASE (k=12)

Equipment Item			Matrix Values $X_{i,j,k}$						
			Equipment Unit Cost In Thousands	Equipment Capacity/Shift In Millions	Avg Unit Tooling Cost ($ in thousands) as $N_{j,k}$ = 1,2,3,....,m				
j	Operation	Machine	(i=1)	(i=2)	(i=3)	(i=4)	(i=5)	(i=6)	(i=7→m)
1	Blank	200T Press	$103.2	.768	6.800	4.925	4.275		→
2	Flatten & Shave	200T Press	103.2	.768	3.800	2.750	2.400		→
3	Wash & Soapcoat	Auto Conveyor	8.0	.653	0				→
4	Precup & Cup	350T Press Hyd	105.6	.653	20.000	14.500	12.600		→
5	Anneal & Cool	Surface Furnace 1x4	50.0	.653	0				→
6	Pickle & Soapcoat	Spec Conveyor 1x4	151.0	.653	0				→
7	1st & 2d Draw	350T Press Hyd	105.6	.653	20.000	14.500	12.600		→
8	3d Draw	75T Press Hyd	95.0	.653	18.000	13.000	11.300		→
9	4th Draw	75T Press Hyd	95.0	.653	18.000	13.000	11.300		→
10	Pierce Primer	22T Horn Press	6.4	.653	3.200	2.300	2.000		→
11	Mouth Harden	75KW Tocco Induction	190.5	.768	3.600				→
12	Stress Relieve	Surface Comb. Furn.	50.0	2.611	0				→
13	Pickle, Wash&Dry	Spec Conveyor	151.0	2.611	0				→
14	Mouth Reduce&Size	75T Press	35.0	.653	6.400	4.850	4.200		→
15	Plate Znphos	Plating Machine	320.0	1.728	13.000				→
16	Paint & Bake	Paint, Conveyor & Oven	50.0	1.128	6.000				→
17	Stamp	20T Horn Press	6.4	.653	1.300				→
18	Carton	Carton Stitcher	2.0	.421	0				→
19	Rough&Finish Trim	10T Horn Press	12.8	.653	3.600	2.600	2.250		→
20	Ream Trim	Power Reamer	4.0	.653	1.500	1.500	1.500	.500	→
21	Rotary Trim	V & O Trimmer	24.0	.653	1.200	.900	.800		→
22	Head	800T Knuckle Press	232.0	.653	20.000	14.500	12.600		→
23	Rough Machine Head	4 Spindle Chucker	117.5	.649	6.000	6.000	6.000	2.000	→
24	Form Shoulder	Leonard Tube Master	6.0	.326	2.400	2.400	2.400	.800	→
25	Finish Head	4 Spindle Chucker	117.5	.447	6.800	6.800	6.800	2.400	→
26	Ream Primer Hole	Drill Press	15.0	.653	1.800	1.300	1.100		→
27	Drill & Chamfer	Drill Press	15.0	.653	1.800	1.800	1.800	.600	→
28	Mark	20T OBI Press	3.2	.653	1.300	.900	.775		→
29	Wash & Dry	Auto Conveyor	8.0	.130	0				→
30	Wash & Dry	Spray Wash & Dry	88.0	.653	5.200				→
31	Test Hardness-100°	Magnetic Tester	17.0	.768	0				→

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TABLE III-14
COST EQUATION SEQUENCE OF SOLUTION FOR IPE, TEST AND MEASURING EQUIPMENT (TME), AND INITIAL TOOLING (IT)--20mm-30mm

		Projectile (HEIT, APT, & TPT) (k=1,2,3)		Link (k=4)		Box (k=5)		LAP (k=6)		Cartridge Case (k=7)		Fuze	
Equation	Factor	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT*
1a1	$N_{i,k}$	1	1	1	1			1	1				
1a2	$Y_{i,k}$	2		2				2					
1a3	Y_k	3		3									
1b1	$N_{i,5}$					1	1						
1b2	$Y_{i,5}$					2							
1b3	Y_5					3							
1c3	Y_6							3					
1d1	$N_{i,7}$									1	1		
1d2	$Y_{i,7}$									2			
1d3	Y_7									3			
1e1	N											1	
1e2	Y											2	
2a2	$Y_{i,k}$		2		2		2		2				

TABLE III-14 (continued)
COST EQUATION SEQUENCE OF SOLUTION FOR IPE, TEST AND MEASURING EQUIPMENT (TME), AND INITIAL TOOLING (IT)--20mm-30mm

		Projectile (HEIT, APT, & TPT) (k=1,2,3)		Link (k=4)		Box (k=5)		LAP (k=6)		Cartridge Case (k=7)		Fuze	
Equation	Factor	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT*
2a3	Y_k		3		3		3		3				
2b2	$Y_{i,7}$										2		
2b3	Y_7										3		

* Fuze initial tooling is included in IPE.

TABLE III-15
COST EQUATION SEQUENCE OF SOLUTION FOR IPE, TEST AND MEASURING EQUIPMENT (TME), AND INITIAL TOOLING (IT) - OVER 30mm-60mm

		Projectile (HET, APT & TP) (k=8,9,10)		LAP (k=11)		Cartridge Case (k=12)		Fuze	
Equation	Factor	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT*
1e1	N							1	
1e2	Y							2	
3a1	$NA_{i,k}$	1	1	1	1				
3a2	$NB_{i,k}$	2	3	2	3	2	2		
3a3	$YA_{i,k}$	3		3					
3a4	$YB_{i,k}$	4		4		5	5		
3a5	Y_k	5							
3b5	$NC_{i,11}$			5	5				
3b6	$YC_{i,11}$			6					
3b7	Y_{11}			7					
3c1	$NA_{i,12}$					1	1		
3c3	$NC_{i,12}$					3	3		

TABLE III-15 (continued)
COST EQUATION SEQUENCE OF SOLUTION FOR IPE, TEST AND MEASURING EQUIPMENT (TME), AND INITIAL TOOLING (IT) - OVER 30mm-60mm

		Projectile (HET, APT & TP) (k=8,9,10)		LAP (k=11)		Cartridge Case (k=12)		Fuze	
Equation	Factor	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT	IPE/TME	IT*
3c4	$YA_{i,12}$					4	4		
3c6	$YC_{i,12}$					6	6		
3c7	Y_{12}					-			
4a2	$YA_{i,k}$		2		2				
4a4	$YB_{i,k}$		4		4				
4a6	$YC_{i,k}$				6				
4a7	Y_k		5		7				
4b7	Y_k						7		

*Fuze initial tooling is included in IPE.

C. DATA COLLECTION

ARMCOM ammunition procurement involves a mixture of ammunition obtained from contractor owned contractor operated (COCO) plants, Government owned contractor operated (GOCO) plants, and Government owned Government operated (GOGO) arsenals. However, most ammunition is procured from GOCO's which support the Government's ammunition needs through the manufacture of propellants, explosives, metal parts, small arms, bag loading, and LAP. Each GOCO is operated by a major US corporation which was selected on the basis of proven success in the management of large production operations. It is a common practice in the Army's ammunition world to find a variety of GOCO's, GOGO's and private companies contributing components toward the final production of a round of ammunition. Thus, the collection of cost and production data involves the accumulation of data generated by a variety of manufacturers.

Data collected for this study were taken from contract-price records and production-delivery schedules available in the ARMCOM Directorates of Procurement and Production and Quality Assurance.

1. Procurement Cost Data

The Summary of Orders and Cost of Deliveries is a record of contract pricing which lists the production quantities and costs for the components ordered. This record is created from a number of source documents furnished by producers and ordering officials. It includes monthly costs and performance reports from the GOCO's, contracts and delivery schedules for private contractors, and funding documents awarded to GOGO's. The summarization of data includes cost and delivery data incurred during the current reporting period and cumulative cost and delivery data incurred from the inception of the procurement order. Data provided are:

- Curre : Deliveries
  - Date of deliveries
  - Quantity delivered
  - Total cost of deliveries
  - Funded cost of deliveries
  - Unfunded or Government furnished material costs
  - Funded unit cost
- Total deliveries to date
  - Cumulative deliveries from inception of order
  - Average unit cost
  - Total cost
  - Total unfunded or Government furnished material cost
  - Total funded cost
  - Funded unit cost

Projectiles, primers, fuzes, cases, propellants and links are analyzed in this study. Tracking quantities and costs from the Summary of Orders and Costs of Deliveries required the analysts to review approximately 3,000 line entries. Capturing quantities and costs for a specific round of ammunition required collecting data according to the components of the round and any related LAP operation. Data were collected from fiscal year 1957 through 1975.

2. Production Quantity Data

The source documents used to capture procurement data were production-delivery schedules and ammunition-data cards. The production-delivery schedule is a monthly report that is prepared by each active GOCO and GOGO. The report provides monthly production rates and final acceptance rates of each item. The ammunition data card is a delivery and acceptance report reflecting quantities shipped by a contractor, GOCO or GOGO.

Collecting production delivery data required an analysis of approximately 10,000 line entries. Analyzed production rates encompassed the review of data generated from fiscal years 1957 through 1975. The review disclosed many instances in which production data were available but corresponding costs could not be collected because of the unavailability of the applicable Summary of Orders and Costs of Deliveries. Annex A demonstrates these differences. Production quantities without corresponding costs were collected to use the data for determining breaks in production.

3. Independent Variables

The independent variables reflected in this study represent a start at finding variables which may be used by a cost estimator to predict recurring ammunition costs. Finding variables which cover the entire spectrum of round sizes is difficult. At the outset of the study, a potential independent-variable list was developed through a coordinated effort between Cost Analysis, Research and Development, and Systems Analysis personnel. The following tables list the potential characteristics and classifications which represent those variables deemed by this group to have high potential as cost drivers.

POTENTIAL CARTRIDGE CHARACTERISTICS

Weight
- Cartridge
- Projectile
- Propellant
- Fuze
- Primer

Volume

Complexity
- Number of parts
- Type of manufacturing

Length

Diameter

Muzzle Velocity
Kinetic Energy

Range
- Maximum
- Effective

Chamber pressure

Muzzle impulse

Desired target effect

Lethal area at 2/3 maximum range

Vulnerable area

Time of Flight

POTENTIAL CLASSIFICATION OF ITEMS AND COMPONENTS

WEAPON-OPERATION CONCEPT
- Recoilless, recoil, gas recoil, and soft recoil

MATERIAL DIFFERENCES
- Steel versus high fragmentation projectiles
- Steel versus brass versus aluminum cartridge cases or caseless
- Single- versus double- versus triple-base propellants

TYPE OF FILL
- TNT, Comp B, Comp C3, etc.

FUZES
- Impact--point or base detonating
- Time--pyrotechnic, mechanical time, electrical time
- Proximity--reliability and accuracy

IMPROVED CONVENTIONAL MUNITIONS
- Number of submunitions
- Complexity of submunitions
- Target effects

MUNITIONS-KILL MECHANISM
- Armor-piercing discarding sabot (APDS)

High-explosive plastic (HEP)
High-explosive antitank (HEAT)
High Explosive (HE)

Of the potential characteristics and classifications, the following characteristics were selected, and quantitative data have been gathered by complete round or ammunition component. The independent variables are segregated by total round and major components. The variables are further segregated into physical characteristics, performance characteristics, and combinations of physical and performance characteristics.

CHARACTERISTICS

TOTAL ROUND CHARACTERISTICS

PHYSICAL	PERFORMANCE	COMBINATIONS OF PHYSICAL AND PERFORMANCE
weight	muzzle velocity	kinetic energy
diameter	range	momentum
volume	chamber pressure	kinetic energy
length		

PHYSICAL COMPONENT CHARACTERISTICS

Projectiles
- Weight
  - Total
  - Explosive

Fuzes
- Number of parts

Cases

LAP

Primers

Propellants
- Weight

There are several independent variables which would appear to be very good. These variables are expressions of target effect, e.g., armor-penetration, fragmentation effect, etc. However, research disclosed that not one of these measures was consistently applied through history. Therefore, these measures, or target effects, have been left for later research. (See section IV).

There are several component characteristics which are known to give good CER's. Two examples are primer weight and surface area of the cartridge case; however, such independent variables are useless to the estimator developing an IPCE in the concept-formulation phase or validation phase of the life cycle. Use of such independent variables was not considered. Two component characteristics used frequently in this study are projectile mass and bore size. Use of these component characteristics is defended on the grounds that target effects can be used to infer projectile mass and bore size; therefore, they become legitimate independent variables.

The following are definitions of variables used in the study:

Weight includes the nominal weight of the complete round and all components with a standard fuze. Fixed rounds include total cartridge weight; semi-fixed and separate rounds include the weights of the total separated components e.g., projectile, case, and propellant.

Range is the maximum distance in yards, or the effective distance which the round can perform its designed function when range is not a criterion. It is the approximate range expected when firing a stationary weapon at the most favorable elevation, under normal atmosphere conditions, with both weapon and projectile impact at sea-level altitude.

Bore Size is the diameter of the bore across the rifling flats of the weapon firing the ammunition.

Muzzle Velocity is the speed of the projectile measured in feet per second.

Projectile Mass is that value determined by dividing projectile weight by the force of gravity, which is 32.2 feet per second squared.

Momentum is a product of projectile mass and muzzle velocity.

Kinetic Energy, an expression of velocity, is the product of muzzle velocity squared and 1/2 the mass.

Chamber Pressure is the pressure limit developed by the propelling charge to produce a specified projectile-muzzle velocity.

In addition to the independent variables developed for the physical and performance characteristics, consideration was given to the quantity, and the cost relationship. Costs may be materially impacted as a result of the quantity of a given round or family of rounds produced in a given year.

Annex D details the independent variable values used in this study for complete round and by component as cross indexed one to another.

D. ANALYSIS OF LEARNING

Application of cost improvement curves adds great flexibility to the estimator's tools. It allows single CER's to be applied easily to a wide range of procurement quantities with relatively simple calculations. Therefore, it became a prime objective of the ammunition cost research project to develop CER's which could be coupled to learning rates wherever possible. To accomplish this objective, several critical questions had to be answered.

What are the proper learning rates to be used for each component assuming that there will probably be more than one producer?

Does level off occur? If it occurs, at what point does it occur?

Do variations in production rates influence the theoretical first-unit cost?

Do variations in production rates influence the learning rate?

Do breaks in production require that adjustments be made for loss of learning in ammunition cost estimates?

1. Methods used for the analysis

a. Normalization of the data for inflation

The historical cost data and estimates contained in Annex A were normalized to FY-74 dollars because the final inflation rate for FY-75 was not available at the time the data were normalized. ARMCOM Circular 37-1 dated 9 June 1975, "Inflation and Price Escalation Instruction for Ammunition," was used for fiscal years 1960 and following. Before FY 60, Wholesale Price Indexes for metal and metal products were applied. These were found in the MICOM publication dated 6 May 1974, "Historical Inflation Indices". The indexes actually used are:

FY	Under 30mm	Over 30mm	FY	Under 30mm	Over 30mm
75	0.83	0.83	66	1.49	1.49
74	1.00	1.00	65	1.53	1.62
73	1.12	1.10	64	1.55	1.68
72	1.18	1.15	63	1.57	1.73
71	1.23	1.22	62	1.58	1.76
70	1.26	1.28	61	1.59	1.78
69	1.41	1.35	60	1.60	1.80
68	1.47	1.42	59	1.59	
67	1.55	1.46	58	1.66	
			57	1.68	

b. Selection of data for calculation of consolidated learning rates

The following criteria were established for selecting historical cost data for running learning curves.

The component must have two or more consecutive years of production cost history.

When production breaks of two or more years occurred, only the production cost history prior to the break was used.

When a production break of one year occurred and a reduced cost was experienced after the production break, the break was ignored.

When the constant-year cost data for FY 73 through FY 75 appeared inordinately high compared to prior years, only production cost history for FY 72 and before was used.

Learning curves were developed for each producer by item within each component. The following criteria were then established for determining which learning curves would be used in developing a composite learning rate.

Individual learning curves of 100 percent or higher were excluded because cost increases are attributed to causes other than learning.

Extreme learning curves in the lower range were also eliminated. Generally, this excluded any learning curves less than 80 percent.

c. Calculations of the composite learning rate

Once the learning results had been screened using the criteria outlined above, composite learning rates by component were determined. The regression form used in developing the composite learning rates is:

$$Y = AX^B$$

To normalize the cost data for each learning curve, the theoretical first-unit cost was set equal to 1.0. The ratio of 1.0 to the original theoretical first-unit cost was applied to the actual lot average unit costs resulting in normalized lot average unit costs. Since the theoretical first-unit costs were set equal to 1.0, the regression form above reduces to:

$$Y = X^B$$

Based upon linear regression theory,

$$B = \frac{\Sigma \ LnY}{\Sigma \ LnX}$$

where: B = Exponent corresponding to the composite learning rate

Y = Normalized lot average unit cost

X = Computed algebraic lot midpoint corresponding to Y.

The composite learning rate was determined using the following equation.

Learning rate = antilog (0.30103 B + 2)

Using the composite learning rates, theoretical first-unit costs were calculated for:

Item producers not included in the composite learning rate determination for which production cost histories were available.

Component items for which historical production cost data were not available necessitating estimates.

2. Results.

a. Composite learning rates:

The composite learning rates developed are as follows:

COMPOSITE LEARNING RATES

Component	Composite Learning Rate	Range	Number Used	Not Used	Not Usable	Total
Projectiles	92.6%	98.9-83.0	35	10	70	115
Cases	94.3%	99.1-82.1	20	7	9	36
Primers						
Percussion	89.7%	98.7-84.9	7	5	2	14
Electric	80.3%	80.3	1	0	5	6
Fuzes	91.1%	99.2-84.0	17	9	33	59

For complete backup detail of this analysis see Annex VE.

Composite learning rates were not obtained for LAP, explosive fill, propellants, and links. This result substantiates the level-off concept, at least for these components. There is insufficient initial production data to establish where level off occurred.

b. Effects of production breaks on learning loss

An increase in the unit cost after a production break is defined as a loss of learning. For ammunition, there is overwhelming evidence that there is not a loss of learning as a result of breaks in production. The following statistical results have been gathered.

	Number of Breaks in Production		Loss of Learning Occurred	
	1 year	More than 1 year	1 year	More than 1 year
Projectiles	6	8	1	0
Cases	4	3	0	0
Primers	5	2	0	1
Fuzes	2	4	0	0
	17	17	1	1

This analysis shows that only two cases of learning loss resulted in thirty-four production breaks examined. Therefore, the estimator should not make adjustments for a learning loss.

c. Effects of variation in production rate

Inspection of the data leads to rejection of the hypothesis that the rate of learning is determined by the production rate. However, as will be seen in the CER portion, section IIIL, production rate is a fairly good predictor of unit costs for LAP. The production rate is correlated with the theoretical first-unit cost, but CER's reflecting this relationship were rejected in favor of statistically superior CER's.

E. DEVELOPMENT OF COST ESTIMATING RELATIONSHIPS AND COST FACTORS

1. Description of Methods of Analysis

The cost estimating relationships (CER's) presented in this study were developed using the Biomedical Multiple Regression with Case Combinations computer program, BMD03R. The computer program is a standard regression analysis package which allows the analyst the flexibility of transforming initial independent and dependent variables to test various equation forms against the desired dependent variable. Also, the analyst can combine independent variables in a logical manner to generate additional independent variables.

Regression analyses using appropriate physical and performance characteristics as independent variables and costs as the dependent variables were performed at the following ammunition component levels:

a. LAP

b. Projectile

c. Explosive fill

d. Case

e. Propellant

f. Primer

g. Link

h. Fuze

CER's providing the best statistical results were further analyzed to determine whether the addition of another independent variable or the transformation of an existing variable improved the statistics.

Because of a relatively large quantity of independent variables including initial variables, variable combinations, and variable transformations, a multitude of ammunition component CER's resulted. To select the best one, the CER's were screened using the following criteria.

The cost-driving or independent variables must make sense. For example, generally the larger the bore size the greater the LAP cost.

The percentage of the total variation explained by the regression equation was required to be high enough to pass the F test at a 99 percent level of significance. If a CER passes the F test at

this level of significance, it is interpreted to mean that the probability is less than 0.01 that the disparity between the calculated explained and unexplained variations is due to chance.

If two or more CER's met criteria a. and b., the CER with the minimum mean absolute percent deviation (MAPD) was selected. MAPD is defined as

$$\frac{1}{N} \sum_{i=1}^{N} \frac{|z_i - \hat{z}_i|}{z_i}$$

where: z_i = actual dependent-variable value
$\hat{z}_i$ = estimated dependent-variable value
N = number of observations

MAPD is interpreted as the average percent that the CER estimated values deviate from the actual values.

The coefficient of variation, defined as the ratio of the standard error of estimate to the mean of the actual dependent-variable values, was minimized. The coefficient of variation is used in comparing two or more CER's possessing the same dependent variable but with a different number of observations. It is emphasized that the dependent variable used in the coefficient of variation needs be exactly the same when comparing CER's.

a. Load Assemble and Pack

Loading, assembling and packing (LAP) costs cover the costs of component assembly into a complete round ready for shipping. These costs include the packing (including steel-ready boxes) and other materials (handling, dunnage, pallets, etc.) normally purchased by the GOCO plant.

The learning curve analysis on LAP costs, section IIID, failed to provide sufficient evidence for developing meaningful theoretical first-unit costs. The LAP regression analysis was, therefore, conducted using the average unit cost published in Annexes A and B as the dependent variable. When more than one LAP contractor produced the same item, the weighted average cost was used.

The data set used for this analysis covered fixed ammunition types in the AP, TP, HE and HEAT categories. Recoilless-rifle round data were excluded due to the differing physical performance principles. HE and HEAT data were combined into a single class since separate treatment would have resulted in insufficient data for both cases.

Results and Recommendations

Preferred predictor: HE and HEAT

$$\ln Z = 6.8639 + 2.1143 \ln X$$

$$\text{or } Z = 0.001045\, X^{2.1143}$$

where: Z = the estimated unit cost in FY-74 dollars
X = the bore size in millimeters

Statistics:

Coefficient of determination = 0.952
Standard error of estimate in Ln form = 0.292
Mean absolute percent deviation = 16.1
Passes F test at 99 percent level of confidence
N = 15

CER DATA

Cartridge	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M56A3 HEI	20	$0.50	$ .59
M246 HEIT-SD	20	0.62	.59
M48 HE	75	9.32	9.62
M352A1 HE	76	9.32	9.90
M348A1 HEAT	90	12.80	14.15
M393A2 HEPT	105	13.18	19.60
M456 HEAT-T	105	13.26	19.60
M71A1 HE*	90	13.42	14.15
M71 HE*	90	13.42	14.15
M431 HEAT-T	90	14.30	14.15
M431A1 HEAT-T	90	15.56	14.15
M431A2 HEAT	90	15.63	14.15
M496 HEAT	76	22.86	9.90
XM657 HET	152	42.88	42.85
XM409 HEAT-TMP	152	50.04	42.85

*Data point duplicated because of a velocity difference between the M71A1 & M71 rounds.

If the anticipated annual production rate significantly deviates from the mean of the rates included in this study's data base, it is recommended that the following formula be used:

$$\ln Z = -4.1294 + 1.6819 \ln X - 0.1743 \ln Y \text{ or}$$

$$Z = 0.01609 X^{1.6819}\, Y^{-0.1743}$$

where: Z = Estimated unit cost in FY-74 dollars

Standard error of estimate in Ln form = 0.351
Mean absolute percent deviation = 23.4
Passes F test at 95 percent level of confidence
N = 12

CER DATA

	Production Rate Per Year (k)	Projectile Mass	Actual Unit Cost	Estimated Unit Cost
M55A2 TP	15,581	0.0068	$0.15	$0.10
M220 TPT	3,802	0.0071	0.17	0.17
M55A1 TPT	3,600	0.0416	0.29	0.54
M206A2 TPT	165	0.0083	0.58	0.52
M63 TP	3,600	0.0500	0.63	0.61
M91 TPT	1,200	0.0609	0.98	0.99
M490 TPT	339	0.6957	7.74	7.20
M456 TPT	51	0.6957	8.64	13.32
M340A1 TPT	60	0.4503	8.80	9.54
M353A1 TPT	238	0.7484	10.51	8.47
M393A1 TPT	69	0.7702	10.89	12.90
M411 TPT	53	1.3322	34.52	20.01

Preferred predictor: AP

$$\ln Z = 2.7627 - 0.00155X + 0.3127\ln Y$$

where: Z = Estimated unit cost in FY-74 dollars
X = Average annual production rate in thousands
Y = Projectile mass

Statistics:
Coefficients of determination
Multiple = 0.915
Partial
ZX.Y = 0.326
ZY.X = 0.082
XY = 0.910
Standard error of estimate is Ln form = 0.343
Mean absolute percent deviation = 24.7
Passes F test at 99 percent level of confidence
N = 7

Cartridge	Production Rate Per Year (k)	Projectile Mass	Annual Unit Cost	Estimated Unit Cost
M81A1 APT	1200	.0609	$ 0.93	$ 1.03
M392A2 APDST	65	.7702	9.06	13.20
M339 APT	16	.4503	10.15	12.04
M318A1 APT	31	.7484	11.19	13.79
M388A1/A2 APT	180	.4087	11.96	9.06
M61A1 APCT	180	.4627	12.93	9.42
M77 APT	180	.7267	14.10	10.85

An attempt was made to improve AP-round estimating by combining the AP and TP data sets. This combination was made to increase data points to 19 from the seven points applicable to the AP rounds. The best resulting form was:

$$\ln Z = 3.8277 - 0.2513 \ln X + 0.7131 \ln Y \text{ or}$$

$$Z = 45.9567\, X^{-0.2513} Y^{0.7131}$$

where: Z = estimated unit cost in FY-74 dollars
X = Average annual production rate in thousands
Y = Projectile mass

Statistics:
Coefficients of determination
Multiple = 0.955
Partial
ZX.Y = 0.404
ZY.X = 0.827
XY = 0.612
Standard error of estimate in Ln form = 0.387
Mean absolute percent deviation = 29.6
Passes F test at 99 percent level of confidence
N = 19

The mean absolute percent deviation is 29.6 and, therefore, is not as acceptable as the preferred forms for either AP or TP estimating.

Similarly, the data for all types of rounds were combined to determine if increasing the level of aggregation would improve the predictive characteristics. The best result was the form:

$$\ln Z = -4.5242 + 1.8218 \ln X - 0.2711 \ln Y \text{ or}$$

$$Z = X^{1.8218} Y^{-0.2711}$$

where: Z = estimated unit cost in FY-74 dollars
X = Bore size in millimeters
Y = Average annual production rate in thousands

X = Bore size in millimeters
Y = Average annual production rate in thousands

Statistics:
Coefficients of determination
Multiple = 0.967
Partial
ZX.Y = 0.828
ZY.X = 0.303
XY = 0.732
Standard error of estimate in Ln form = 0.253
Mean absolute percent deviation = 18.4
Passes the F test at the 99 percent level of confidence
N = 15

CER DATA

Cartridge	Bore Size(mm)	Production Rate Per Year(k)	Actual Unit Cost	Estimated Unit Cost
M56A3 HEI	20	19,987	$ 0.50	$ 0.44
M246 HEIT-SD	20	1,357	0.62	0.71
M48 HE	75	48	9.32	11.68
M352A1 HE	76	48	9.32	11.94
M348A1 HEAT	90	120	12.80	13.52
M393A2 HEPT	105	82	13.18	18.73
M456 HEAT-T	105	102	13.26	18.03
M71A1 HE	90	180	13.42	12.60
M71 HE	90	180	13.42	12.60
M431 HEAT-T	90	120	14.20	13.52
M431A1 HEAT-T	90	120	15.56	13.52
M341A2 HEAT	90	120	15.63	13.52
M496 HEAT	76	25	22.86	13.38
XM657 HEI	152	18	42.88	45.44
XM409 HEAT-MP	152	43	50.04	39.04

Preferred predictor: IP

$$\ln Z = 4.1000 - 0.3247 \ln X + 0.6453 \ln Y \text{ or}$$

$$Z = 60.3403\, X^{-0.3247} Y^{0.6453}$$

where Z = estimated unit cost in FY-74 dollars
X = average annual production rate in thousands
Y = Projectile mass

Statistics:
Coefficients of determination
Multiple = 0.972
Partial
ZX.Y = 0.639
ZY.X = 0.878
XY = 0.588

Statistics:

Coefficients of determination

Multiple = 0.924

Partial

ZX.Y = 0.690

XY.X = 0.304

XY = 0.652

Standard error of estimate in Ln form = 0.460

Mean absolute percent deviation = 38.1

Passes F test at 99 percent level of confidence

N = 34

The mean absolute deviation is 38.1, making the summary level of estimating LAP cost inferior to all individual forms.

b. Projectiles

Projectile metal parts costs include procurement costs of all body parts, excluding fuze parts, going into the LAP operations. The costs include profit and fees.

Since learning was encountered in projectile procurement, section IIIB, the projectile dependent variable is the theoretical first-unit cost. When cost data were available for more than one producer, the theoretical first-unit cost included in the regression analyses was an average of the theoretical first unit costs of all producers.

The theoretical first unit costs for HE, AP and TP round types were regressed against all reasonable independent variables resulting in the Ln of the theoretical first unit cost versus the Ln of bore size proving to be best cost predictor. The addition of velocity related variables, momentum and kinetic energy, was attempted to increase coefficients of determination. However, analysis of the equation forms resulted in illogical relationships since the theoretical first-unit cost varied inversely with velocity related variables. These forms were, therefore, rejected.

The HE preferred predictor includes ammunition rounds for medium-bore, tank, recoilless-rifle and howitzer applications. The AP preferred predictor includes rounds for medium-bore, tank and howitzer applications. The TP preferred predictor includes rounds for medium-bore and tank applications. The recommended predictors are:

Preferred predictor: HE

$$\ln Z = -1.6983 + 1.3739 \ln X \text{ or}$$

$$Z = 0.1830\, X^{1.3739}$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.742
Standard error of estimate in Ln form = 0.501
Mean absolute percent deviation = 38.6
Passes F test at 99 percent level of confidence
N = 16

CER DATA

	Bore Size	Actual First-Unit Cost	Estimated First-Unit Cost
M56A3 HEI	20	8.27	11.22
M306A1 HE	57	94.45	47.30
M66 HE	75	127.51	68.96
M48 HE	75	62.86	68.96
M352/A1 HE	76	63.59	70.22
M71/A1 HET	90	68.88	88.59
M1 HE	105	44.04	109.49
M356 HET	120	183.86	131.53
XM657 HET	152	217.07	182.00
M107 HE	155	100.47	186.96
M449 HE	155	114.69	186.96
M549 HE	155	227.92	186.96
M483 HE	155	466.49	186.96
M437 HE	175	197.74	220.88
M106 HE	203	269.53	270.84
M404 HE	203	259.01	270.84

Preferred predictor: AP

$\ln Z = -3.9018 + 1.7971 \ln X$ or

$Z = 0.02021\, X^{1.7971}$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Bore size in millimeters

Statistics:

Coefficient of determination = 0.943
Standard error of estimate in Ln form = 0.272
Mean absolute percent deviation = 17.2
Passes F test at 99 percent level of confidence
N = 8

CER DATA

	Bore Size	Actual First-Unit Cost	Estimated First-Unit Cost
M53 API	20	4.47	4.40
M81A1 APT	40	15.42	15.29
M61A1 APCT	75	38.59	47.33
M338A1/A2 APT	75	33.91	47.33
M339 APT	76	55.34	48.47
M318A1 APT	90	107.80	65.68
M77 APT	90	68.56	65.68
M358 APT	120	94.09	110.15

Preferred predictor: TP

$$\ln \hat{Z} = -5.5868 + 2.1305 \ln X \text{ or}$$

$$\hat{Z} = 0.003747\ X^{2.1305}$$

where: $\hat{Z}$ = Estimated theoretical first-unit cost in FY-74 dollars
X = Bore size in millimeters

Statistics:
Coefficient of determination = 0.951
Standard error of estimate in Ln form = 0.385
Mean absolute percent deviation = 32.0
Passes F test at 99 percent level of confidence
N = 10

CER DATA

	Bore Size	Actual First-Unit Cost	Estimated First-Unit Cost
M55A2 TP	20	3.26	2.22
M212 TPT	20	2.00	2.22
M221 TPT	20	1.43	2.22
M63 TP	37	10.43	8.22
M55A1 TPT	37	9.50	8.22
M91 TPT	40	12.82	9.70
M340A2 TPT	76	21.80	38.09
M353 TPT	90	37.96	54.61
M489 TPT	105	71.08	75.83
M411A1 TPT	152	269.01	166.78

c. Explosive Fill

Explosive Fill is placed within the projectile to achieve a desired target effect. The explosive fill cost predictors only cover the use of composition B, TNT, and in a very few instances, composition A-3.

A learning curve analysis did not provide sufficient evidence for the development of theoretical first-unit costs. The costs used are only from the latest years of manufacture because TNT production has undergone a dramatic change in technology. The manufacturing process has switched from the batch method to an automated method. Coincidentally, there has been a lowering of demand for TNT. And the cost of petroleum, of which TNT is a product, has risen faster than the escalation factors would indicate. The sum effect of these changes resulted in the decision to use the latest production prices rather than 1960-1970 historical costs.

The independent variable best suited for estimating explosive fill costs is bore size. Other factors affecting the explosive fill costs were not available for all rounds and, therefore, not suitable.

Results and Recommendations

Preferred predictor: HEAT

$LnZ = -12.3829 + 2.6706 \ LnX$ or

$Z = (4.1896 \times 10^{-6}) \ X^{2.6706}$

where: Z = Estimated unit cost in FY-74 dollars
X = Bore size in millimeters

Statistics:

Coefficient of determination = 0.944
Standard error of estimate in Ln form = 0.150
Mean absolute percent deviation = 10.0
Passes F test at 99 percent level of confidence
N = 10

CER DATA

Cartridge	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M310A1 HEAT	75	$0.43	$0.43
M66 HEAT-T	75	0.43	0.43
M496 HEAT-T	76	0.47	0.44
M371 HEAT	90	0.74	0.69
M431 HEAT	90	0.52	0.69
M348A1 HEAT	90	0.67	0.69
M324 HEAT-T	105	1.32	1.05
M456 HEAT-T	105	0.92	1.05
M344A1 HEAT	106	1.20	1.07
XM409E5 HEAT-T	152	2.71	2.81

Preferred predictor: HE

$$\text{Ln}Z = -13.7934 + 3.0791\ \text{Ln}X$$

$$Z = (1.0224 \times 10^{-6})\ X^{3.0791}$$

where: Z = Estimated unit cost in FY-74 dollars
X = Bore size in millimeters

Statistics:

Coefficient of determination = 0.831
Standard error of estimate in Ln form = 0.571
Mean absolute percent deviation = 38.7
Passes F test at 99 percent level of confidence
N = 23

CER DATA

Cartridge	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
MK2 HE	40	$0.06	$0.09
M306A1 HE	57	0.24	0.26
M307A1 HE	57	0.17	0.26
M48 HE	75	0.59	0.60
M42A1 HE	76	3.87	0.63
M352 HE	76	0.63	0.63
M71A1 HE	90	0.92	1.06
M71 HE	90	0.63	1.06
M501 HE	90	0.90	1.06
M323 HE	105	1.88	1.71
M1 HE	105	2.14	1.71
M413 HE	105	0.47	1.71
M548 HE	105	2.21	1.71
M3A1 HE	107	3.08	1.81
M329 HE	107	3.08	1.81
M469 HE-T	120	1.94	2.58
M356 HE-T	120	3.41	2.58
M657E2 HE-T	152	3.76	5.34
M101 HE	155	6.20	5.67
M107 HE	155	5.78	5.67
M549 HE	155	6.88	5.67
M103 HE	203	8.28	13.01
M106 HE	203	14.32	13.01

Preferred predictor: HEPT

$$\text{Ln}Z = -3.7946 + 0.05190X$$

where: Z = Estimated unit cost in FY-74 dollars
X = Bore size in millimeters

Statistics:

Coefficient of determination = 0.773
Standard error of estimate in Ln form = 0.424
Mean absolute percent deviation = 29.9
Passes F test at 99 percent level of confidence
N=8

CER DATA

Cartridge	Bore Size(mm)	Actual Unit Cost	Estimated Unit Cost
M309A1 HEPT	75	$0.59	$1.10
M349 HEPT	75	2.07	1.10
M326 HEPT	105	6.08	5.23
M345 HEPT	105	6.25	5.23
M327 HEPT	105	3.27	5.23
M393A1 HEPT	105	5.18	5.23
M393A2 HEPT	105	5.35	5.23
M346A1 HEPT	106	6.25	5.51

In addition to treating the round types separately, HEAT, HE, and HEPT rounds were combined into a single CER. Also, HE and HEPT rounds were combined into a single CER. The results of these combinations were statistically inferior to the independent treatment of each type and are, therefore, not recommended.

d. Cases

Case costs include the cost of procurement from vendors. The learning curve analysis, section IIID, yielded the conclusion that case procurement is affected by learning. Therefore, the case regression analyses used the theoretical first-unit cost of each case as the dependent variable. The theoretical first-unit costs for cases having multiple producers are averages of all producers.

Independent variables considered include bore size, length, surface area, projectile mass, momentum, kinetic energy, and various combinations of the above. Although charge weight was considered, this would be difficult for the estimator to determine. Round pressure was considered but the data were incomplete. The cartridge cases were segregated into categories of brass and steel.

The results achieved on brass and steel cases were poor for the primary independent variables. Significant results were achieved on brass cases using surface area as an independent variable. Surface area as defined in this study, is dependent on case length and bore size. The results of this regression derived from surface area are included secondarily because the CLR is the best cost predictor when case length is known.

The preferred predictor for brass cases includes fixed HE, HEAT, AP, and TP ammunition rounds for medium-bore and tank applications. The preferred predictor for steel cases includes fixed HE, HEAT, AP, and TP ammunition rounds for medium-bore, tank, and recoilless-rifle applications.

Preferred predictor: Brass cases

$$\ln Z = 0.6833 + 0.02671\,X + 0.5731\,Y$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Bore size in millimeters
Y = Projectile mass

Statistics:
Coefficients of determination
Multiple = 0.870
Partial
ZX.Y = 0.430
ZY.X = 0.0551
XY = 0.822
Standard error of estimate in Ln form = 0.469
Mean absolute percent deviation = 40.3
Passes F test at 99 percent level of confidence.
N = 28

CER DATA

Case Model	Complete Round	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
MK1A2	M54A1HE/M55A1TPT	37	0.0416	$ 2.52	$ 5.45
	M80APT	37	0.0516	2.52	5.49
	M53TP	37	0.0500	2.52	5.48
M103	M52APIT	20	0.0087	3.58	3.40
	M55A2/M242API	20	0.0068	3.58	3.39
	M56A3 HEI	20	0.0070	3.58	3.39
	M220TPT	20	0.0071	3.58	3.39
	M246HEIT	20	0.0085	3.58	3.40
M18	M338A1APT	75	0.4087	9.55	18.60
	M48HE	75	0.4565	9.55	19.11
M25	M81A1APT	40	0.0609	10.33	5.98
M17	M54A1HE/M55A1	37	0.0416	10.77	5.45
	M59APC	37	0.0593	10.77	5.51
T27E2	M34A1HEAT	90	0.4472	21.44	28.39
M88	M339APT	76	0.4503	24.27	19.56
	M352A1HE	76	0.4658	24.27	19.74
	M331A1/A2HVAPDST	76	0.2553	24.27	17.49
M115	M392A1/A2APDST	105	0.7702	36.29	51.03
	M494APERS	105	0.9565	38.66	56.77
	M467/M468TPT	105	0.7702	38.66	51.03
M19	M71A1HE	90	0.7267	47.36	33.33
	M77APT	90	0.7267	47.36	33.33
	M304HVAPT	90	0.5202	47.36	29.61
	M332A1HVAP	90	0.3863	47.36	27.42
M108	M353A1TPT	90	0.7484	48.77	33.74
M111	M469HEAT-T	120	0.9658	73.53	85.24
M109	M358APT/M359TPT	120	1.5807	128.31	121.25
	M356HET	120	1.5652	128.31	120.18

Given: Case length has been defined

Preferred predictor: Brass cases

$$\ln Z = 1.1857 - 0.1255 \ln X + 0.02125\, Y$$

where: Z = Estimated theoretical first-unit cost in FY- dollars
X = Momentum
Y = Surface area in square inches

Statistics:
Coefficients of determination
Multiple = 0.955
Partial
ZX.Y = 0.065
ZY.X = 0.732
XY = 0.908

Standard error of estimate in Ln form = 0.275
Mean absolute percent deviation = 20.1

Passes F test at 99 percent level of confidence
N = 28

Note: Surface area is defined as the sum of the perpendicular cross-sectional area of the case cylinder and the area of the case cylinder. The case cylinder has diameter equal to the bore size. The formula is:

Area = $\pi r^2 + 2\pi rL$
where: r = Case cylinder radius in inches
L = Case length in inches.

The millimeter-to-inch conversion factor is 0.03937.

CER DATA

Case Model		Complete Round	Momentum	Case Surface Area (in^2)	Actual First-Unit Cost	Estimated First-Unit Cost
MK1A2	47mm	M54A1 HE/M55A1 TPT	108.160	24.537	$ 2.52	$ 3.06
		M80 APT	94.170	24.537	2.52	3.12
		M63 TP	130.000	24.537	2.52	2.[illegible]
M103	20mm	M52 APIT	29.406	25.683	3.58	3.[illegible]
		M55A2/M242 API	22.984	25.683	3.58	3.81
		M56A3 HEI	23.660	25.683	3.58	3.80
		M220 TPT	23.998	25.683	3.58	3.79
		M246 HEIT	28.730	25.683	3.58	3.71
M18	75mm	M338A1 APT	866.440	93.681	9.55	10.26
		M48 HE	890.175	93.681	9.55	10.22
M25	40mm	M81/A1 APT	174.783	78.854	10.33	9.15
M17	37mm	M54A1 HE/M55A1 TPT	108.160	56.644	10.77	6.66
		M59 APC	121.565	56.644	10.77	5.97
T27E2	90mm	M348A1 HEAT	1,252.160	158.772	21.44	39.05
M88	76mm	M339 APT	1,440.960	150.477	24.27	32.16
		M352A1 HE	1,117.920	150.477	24.27	33.21
		M331A1/A2 HVAP-DST	1,053.113	150.477	24.27	33.45
M115	105mm	M392A1/A2 APDST	3,735.470	166.166	36.29	39.83
		M494 APERS	2,582.550	166.166	38.66	41.72
		M467/M468 TPT	1,848.180	166.166	38.66	43.51
M19	90mm	M71A1 HE	1,744.080	158.772	47.36	37.46
		M77 APT	1,962.090	158.772	47.36	36.91
		M304 HVAPT	1,742.670	158.772	47.36	37.46
		M332A1 HVAP	1,496.913	158.772	47.36	38.18
M108	90mm	M353A1 TPT	2,245.200	158.772	48.77	36.29
M111	120mm	M469 HEAT-T	3,621.750	180.704	73.53	54.47
M109	120mm	M358 APT/M359 TPT	5,532.450	223.619	128.31	128.53
		M356 HET	3,913.000	223.619	128.31	134.26

Preferred predictor: Steel cases

$$\ln Z = 1.0625 + 0.02063\ X + 0.2022\ Y$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Bore size in millimeters
Y = Projectile mass

Statistics:
Coefficients of determination
Multiple = 0.543
Partial
ZX.Y = 0.332
ZY.X = 0.006
XY = 0.716
Standard error of estimate in Ln form = 0.444
Mean absolute percent deviation = 40.3
Passes F test at 99 percent level of confidence
N = 26

CER DATA

Case Model	Complete Round	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
M204	M206A1 TPT	20	0.0083	$ 4.35	$ 4.38
M18B1	M338A2 APT	75	0.4087	6.81	14.76
M25B1	M81APT	40	0.0609	8.05	6.68
M17B1	M18 APT/M353 TPT	90	0.7484	10.68	21.54
M108B1	M336 CSTR	90	0.7233	10.68	21.44
	M337 CSTR	90	0.6351	10.68	21.06
M171	M496 HEAT-T	76	0.2879	11.79	14.71
M115B1	M391A1/A2 APDST	105	0.7702	17.28	29.49
	M728 APDST	105	0.4435	17.28	27.60
	M724 TPDST	105	0.2658	17.28	26.63
M88B1	M339 APT/M340A1E1 TPT	76	0.4503	19.57	15.20
	M35A1 HE	76	0.4658	19.57	15.24
	M363 CSTR	76	0.4565	19.57	15.22
	M331A1/A2 HVAP-DST	76	0.2553	19.57	14.61
M200	M580 APERST	90	0.6522	20.10	21.13
M93B1	M344A1 HEAT	106	0.5466	24.24	28.77
M19B1	M71/A1 HET	90	0.7267	28.39	21.45
	M31A1 APT	90	0.7484	28.39	21.54
	M332A1 HVAPT	90	0.3863	28.39	20.02
M148A1B1	M490 TPT	105	0.6957	29.77	29.05
M114A1	M431A1/A2 HEAT	90	0.4037	31.96	20.09
M94B1	M581 APERST	106	0.6670	41.32	29.48
	M344A1 HEAT	106	0.5466	41.32	28.77
	M346 HEPT	106	0.5435	41.32	28.75
M150B1	M467 TPT	105	0.7702	50.70	29.49
	M494 APERS	105	0.9565	50.70	30.65

e. Propellants

The propellant cost covers the cost of propellant manufacturing only. The learning curve analysis, section IIIB, failed to provide evidence of learning application to propellant costs; therefore, propellants were priced at the average unit cost shown in annex A. When several producers made the same propellant, the weighted average cost was used. When there was more than one propellant for a given round, costs for all propellants were used. When cost data were unavailable for a specified web thickness of a given type of propellant, the cost data of the web thickness closest to the web thickness specified for a round were used.

The data used for this analysis covered fixed ammunition types. Below is a table showing the derivation of propellant costs per round in FY-74 dollars.

PROPELLANTS

Round Model	Bore Size	Type of Propellant	Propellant Weight (lb)	Propellant Cost per Pound	Actual Cost of Propellant
M220	20mm	WC 870	0.087	$ 0.920	$ 0.08
M242	20mm	WC 870	0.085	0.920	0.08
M56A3	20mm	WC 870	0.085	0.920	0.08
M52E1	20mm	WC 870	0.085	0.920	0.08
M246	20mm	WC 870	0.086	0.920	0.08
M206A1	20mm	CR 8325	0.110	1.682	0.19
M55	37mm	M1 SP	0.340	0.781	0.27
M63	37mm	M1 SP	0.560	0.781	0.44
M81A1	40mm	M1 MP	0.650	0.757	0.49
MK2	40mm	M1 MP	0.720	0.757	0.49
M72	75mm	M1 SP	1.900	0.781	1.48
M48	75mm	M1 SP	1.930	0.781	1.51
M61A1	75mm	M1 MP	2.000	0.757	1.51
M352A1	76mm	M6 MP	3.640	0.752	2.74
M363	76mm	M6 MP	5.000	0.725	3.63
M496	76mm	M6 MP	5.060	0.725	3.67
M348	90mm	M1 MP	5.000	0.757	3.79
M71A1	90mm	M1 MP	5.310	0.757	4.02
M467	105mm	M1 MP	5.900	0.757	4.47
M338A1/A2	75mm	M17	2.100	2.258	4.74
M71	90mm	M6 MP	7.300	0.725	5.29
M339	76mm	M30 MP	5.600	1.015	5.68
M336	90mm	M6 MP	8.000	0.752	6.02
M337	90mm	M6 MP	8.500	0.725	6.16
M589	90mm	M6 MP	8.800	0.725	6.38
M353A1	90mm	M6 MP	8.600	0.752	6.47

M494	105mm	M6 MP	9.200	0.725	6.67
M431A1/A2	90mm	M30 MP	8.250	0.947	7.81
M318A1	90mm	M30 MP	8.600	0.934	8.03
M724	105mm	M30 MP	9.000	0.925	8.33
M318	90mm	M17	8.600	0.942	9.42
M456A1/E1	105mm	M39 MP	11.500	0.947	10.89
M392	105mm	M30 MP	12.000	0.925	11.10
M728	105mm	M30 MP	12.000	0.947	11.36
M469	120mm	M6 MP	23.000	0.725	16.68
M356	120mm	M31	12.400	1.709	21.19
M358	120mm	M17	29.000	2.258	65.48

An initial survey was run on all the above data for the linear and curvelinear regression forms covering the logical independent variables. The following preferred predictor resulted.

Preferred predictor: Propellant

$LnZ = -10.5840 + 0.01571\ X + 0.7416\ LnY$

where: Z = Unit cost in FY-74 dollars

X = Bore size in millimeters

Y = Kinetic energy

Statistics:
- Coefficients of determination
  - Multiple = 0.968
  - Partial
    - ZX.Y = 0.120
    - ZY.X = 0.469
    - XY = 0.944
- Standard error of estimate in Ln form = 0.332
- Mean absolute percent deviation = 23.3
- Passes F test at 99 percent level of confidence
- N = 37

CLR DATA

Round Model	Bore Size (mm)	Kinetic Energy	Actual Cost	Estimated Unit Cost
M220	20	40,557	$ 0.08	$ 0.09
M242/M55A2/M53	20	38,843	0.08	0.09
M56A3	20	39,985	0.08	0.09
M52E1	20	49,606	0.08	0.11
M246	20	48,554	0.08	0.10
M206A1	20	48,236	0.19	0.10

M55	37	140,608	0.27	0.30
M63	37	169,000	0.44	0.34
M81/A1	40	250,814	0.49	0.48
MK2/M91	40	250,814	0.5[illegible]	0.48
M72	75	891,969	1.48	2.13
M48HE	75	356,641	1.51	2.23
M61A1	75	953,370	1.51	1.08
M352A1	76	1,341,504	2.74	2.93
M363	76	1,314,720	3.63	2.88
M496	76	1,814,130	3.67	3.66
M348	90	1,753,024	3.79	4.44
M71	90	2,648,822	4.02	6.03
M467/M393	105	2,218,176	4.47	6.69
M338	75	918,431	4.74	2.17
M71	90	2,648,822	5.29	6.03
M399/M340	76	2,305,536	5.68	4.37
M336	90	2,978,875	6.02	6.58
M377	90	2,763,479	6.16	6.22
M580	90	2,924,900	6.38	6.51
M353	90	3,367,800	6.47	7.21
M494	105	3,486,443	6.67	9.36
M431	90	3,149,365	7.81	6.86
M318	90	3,367,800	8.03	7.21
M724	105	3,389,282	8.33	9.17
M318/M353	90	3,367,800	9.42	7.21
M456/M490	105	5,156,007	10.89	12.51
M392	105	9,058,515	11.10	19.01
M728	105	4,856,857	11.36	11.97
M469	120	6,790,781	16.68	19.43
M356	120	4,891,250	21.19	15.23
M358/M359	120	9,681,788	65.48	25.27

f. Primers

The cost of primers as collected for this study includes profit and fee. The costs used as dependent variables are the theoretical first-unit costs as derived in the learning analysis, section IIID.

Analysis of all regression forms used for all reasonable independent variables revealed only weak relationships at best. Since it is a common engineering practice to try to use an available production primer rather than to create a new design for a new family of ammunition, it is unlikely to find primers specifically related to a complete round's performance characteristics. The alternative to using CER's is to use broad averages or analogies with a similar primer. Fortunately, primers are a small part of the total round cost; therefore, the use of CER's is preferred even though variations may be quite wide.

Preferred predictor: Percussion primers

$$\ln Z = 2.7957 - 2.2678 \ln X + 1.3338 \ln Y \text{ or}$$

$$Z = 16.3741\, X^{-2.2678}\, Y^{1.3338}$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application momentum

Statistics:
Coefficients of determination
Multiple = 0.645
Partial
ZX.Y = 0.096
ZY.X = 0.226
XY = 0.972
Standard error of estimate in Ln form = 0.569
Mean absolute percent deviation = 44.3
Passes F test at 99 percent level of confidence
N = 17

CER DATA

Primer Model	Bore Size(mm)	Momentum	Actual First-Unit Cost	Estimated First-Unit Cost
M115	20	28.33	1.70	1.60
M181A2	57	554.92	3.29	7.80
M38A1	37	108.19	3.43	2.35
M23A2	40	174.78	3.43	3.73
M22A3	75	570.63	3.43	4.35
M38B2	40	174.78	5.21	3.73
M81	76	1022.05	5.43	9.18
M68	76	1117.92	5.43	10.34
M68	90	1252.16	5.43	8.20

Primer Model	Bore Size(mm)	Momentum	Actual First-Unit Cost	Estimated First-Unit Cost
M62	76	1095.60	7.70	10.07
M58	76	1440.96	13.08	14.51
M58	90	2245.20	13.08	17.87
M96	120	3621.75	14.07	17.61
M79	90	1594.62	18.37	11.32
M79	90	1614.80	18.37	11.51
M28B2	90	1744.08	36.63	12.76
M28B2	90	1962.09	36.63	14.93

Preferred predictor: Electric primers

$$\ln Z = -14.1220 + 4.0538 \ln X - 0.9031 \ln Y \text{ or}$$
$$Z = (7.3603 \times 10^{-7})\, X^{4.0538}\, Y^{-0.9031}$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

Statistics:
Coefficients of determination
Multiple = 0.797
Partial
ZX.Y = 0.399
ZY.X = 0.201
XY = 0.972
Standard error of estimate in Ln form = 0.748
Mean absolute percent deviation = 61.3
Passes F test at 99 percent level of confidence
N = 13

CLR DATA

Primer Model	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
M52A3B1	20	0.0068	$10.48	$12.54
M52A3B1	20	0.0070	10.48	12.21
M52A3B1	20	0.0087	10.48	10.04
M52A3B1	20	0.0089	10.48	9.84
M67	120	0.9658	59.50	203.75
M67	120	1.5652	59.50	131.75
M67	120	1.5807	59.50	130.58
M86	105	0.7702	277.07	145.47
M86	105	0.9565	277.07	119.62
M80A1	105	0.2658	280.28	380.23
M80A1	105	0.4435	280.28	239.47
M80A1	105	0.7702	280.28	145.47
M83	105	0.6957	453.91	159.47

g. Links

The learning curve analysis, section IIID, failed to provide sufficient evidence that link production is affected by learning. Therefore, the weighted average unit cost for all producers was determined for each link. The table below shows these data.

Link Model	Bore Size	Quantity	Weighted Average Unit Cost in FY-74 dollars
M1	7.62mm	621,516,075	$0.0120
M13	7.62mm	5,091,158,064	0.0133
M9	12.7mm	169,074,544	0.0265
M15	12.7mm	68,001,281	0.0669
M14	20mm	215,684,556	0.1592
M22	20mm	1,500,000	0.1904
M12	20mm	85,329,748	0.2368
M17	20mm	2,624,000	0.3785
M16	40mm	43,402,720	0.2645

The above cost data were regressed against bore size. This regression showed the best form to be $Y = AX^B$, with a 0.802 coefficient of determination. Based on the F test, the coefficient of determination is significant at the 99 percent confidence level. However, further analysis resulted in a mean absolute deviation of 51.42 percent which is undesirably high. Inspection of the data indicated that other independent variables such as round weight and muzzle velocity would not be superior to bore size.

The costs were then grouped by bore size and an average unit cost for each was found. Using these averages as estimators, the mean absolute deviation is 28.17 percent. The following chart is the result.

Bore Size	Average Cost
7.62mm	$0.0127
12.7mm	0.0467
20mm	0.2413
40mm	0.2645

For rounds with bore sizes other than those shown above, interpolation is suggested. It is unlikely that links would be required on rounds with a bore size greater than 40mm.

h. FUZES

Fuze costs include the cost of procurement of metal parts in addition to the fuze n LAP. In some instances, fuze metal parts are procured from a vendor and assembled at an Army ammunition plant.

The learning curve analysis, section IIID, yielded the conclusion that fuze procurement is affected by learning. Therefore, the fuze regression analyses used the theoretical first-unit cost of each fuze as the dependent variable. Theoretical first-unit costs for fuzes having multiple producers are averages of all producers.

The data used for these analyses covered fixed ammunition types in the AP, TP, HE and HEAT categories. Recoilless-rifle and mortar-round data were included in the initial runs and excluded in subsequent runs because their independent variables differed widely from other fixed-round independent variables. The results achieved, excluding recoilless rifles and mortars, were more significant for base-detonating and point-initiating-base-detonating fuzes.

An initial survey of all independent variables was conducted to determine the regression forms to be subjected to further research. The independent variables were segregated by fuze type into point detonating (PD), base detonating (BD), point initiating-base detonating (PIBD), mechanical time (MT), mechanical time, superquick (MTSQ), and combinations of BD and PIBD as well as MT and MTSQ. Independent variables included bore size, mass, kinetic energy, momentum, and various combinations of the above.

Analysis of all forms revealed only weak relationships. The weakness of the relationship is most likely a result of the practice of using a single fuze for a wide range of ammunition.

Preferred predictor: Point-detonating fuzes

$$\ln Z = 14.0768 - 2.2258 \ln X + 1.0590 \ln Y \text{ or}$$

$$Z = 1{,}298{,}603\, X^{-2.2258}\, Y^{1.0590}$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

Statistics:
Coefficients of determination
Multiple = 0.583
Partial
ZX.Y = 0.163
ZY.X = 0.175
XY = 0.988

Standard error of estimate in Ln form = 0.518
Mean absolute percent deviation = 45.2
Passes F test at 99 percent level of confidence
N = 33

CER DATA

Fuze Model	Complete Round	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
M505A3	M210 HEI	20	0.0088	$ 6.01	$10.99
	M242 HEI	20	0.0068	6.01	8.36
	M56A3 HEI	20	0.0070	6.01	8.62
	M246 HEI	20	0.0085	6.01	10.59
M572	M437 HE	175	0.5885	13.91	66.32
M71	MK2 HET	40	0.0609	17.55	18.22
XM720	XM657A2 HET	152	1.3106	21.10	24.07
M78	M1 HE	105	1.0248	28.77	42.26
	M107 HE	155	2.9503	28.77	54.43
	M106 HE	203	6.2112	28.77	65.68
M51A4/A5	M334 HE	75	0.3792	53.65	31.19
	M1 HE	105	1.0248	53.65	42.26
	M107 HE	155	2.9503	53.65	54.43
	M101 HE	155	2.9503	53.65	54.43
	M106 HE	203	6.2112	53.55	65.68
	M103 HE	203	7.4531	53.65	79.67
	M352A1 HE	76	0.4658	53.65	37.65
	M42A1 HE	76	0.3975	53.65	31.83
	M71A1 HE	90	0.7267	53.65	41.39
	M48 HE	75	0.1565	53.65	37.96
M557	M48 HE	75	0.4565	54.34	37.96
	M71A1 TP	90	0.7267	54.34	41.39
	M356 HET	120	1.5652	54.34	49.17
	M411 TPT	152	1.3323	54.34	24.50
	M1 HE	105	1.0248	54.34	42.26
	XM548 RAP HE	105	0.8851	54.34	36.19
	XM606 HE	105	0.8851	54.34	36.19
	M107 HE	155	2.9503	54.34	54.43
	XM549 RAP HE	155	2.9814	54.34	55.04
	M101 HE	155	2.9503	54.34	54.43
	M106 HE	203	6.2112	54.34	65.68
M48A3	M48 HE	75	0.4565	77.01	37.96
	M35A1 HE	76	0.4658	77.01	37.65

Results and Recommendations

Preferred predictor: Base detonating fuzes

$$\ln Z = 0.6493 + 0.5905 \ln X + (2.0698 \times 10^{-7}) Y$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application kinetic energy

Statistics:
Coefficients of determination
Multiple = 0.685
Partial
ZX.Y = 0.330
ZY.X = 0.264
XY = 0.372
Standard error of estimate in Ln form = 0.260
Mean absolute percent deviation = 19.3
Passes F test at 95 percent level of confidence
N = 9

CER DATA

Fuze Model	Complete Round	Bore Size(mm)	Kinetic Energy	Actual First-Unit Cost	Estimated First-Unit Cost
M58	M63 HE	37	169,000	$15.61	$16.72
M66A2	M61A1 APCT	75	953,370	27.55	29.85
	M62A1 APCT	76	1,616,316	27.55	34.51
	M67 HEAT-T	105	698,750	27.55	34.54
M91A1	M66 HEAT	75	207,600	29.63	25.58
	M327 HEPT	105	1,228,700	29.63	38.54
M62	M66 HEAT-T	75	207,600	36.14	25.58
M578	M393 HEAT	105	2,218,176	54.37	47.31
M48A3	M393 HEAT	105	2,218,176	60.18	47.30

Preferred predictor: Point-initiating-base-detonating fuze

$$\ln Z = -52.3486 + 11.5814 \ln X - 4.0205 \ln Y \text{ or}$$

$$Z = (1.8420 \times 10^{-23})\, X^{11.5814}\, Y^{-4.0205}$$

where: Z = Estimated theoretical first-unit cost in FY-74 dollars
X = Round application bore size in millimeters
Y = Round application projectile mass

Statistics:
Coefficients of determination
Multiple = 0.897
Partial
ZX.Y = 0.823
ZY.X = 0.756
XY = 0.968
Standard error of estimate in Ln form = 0.265

Mean absolute percent deviation = 16.0
Passes F test at 97.5 percent level of confidence
N = 7

CER DATA

Fuze Model	Complete Round	Bore Size(mm)	Projectile Mass	Actual First-Unit Cost	Estimated First-Unit Cost
M569A1	M495 HEAT-T	76	.2879	$ 21.23	$ 16.67
	M348 HEAT-T	90	.4472	21.23	20.11
	M431A1 HEAT	90	.4037	21.23	30.34
	M456 HEAT-T	105	.6957	21.23	20.28
	XM622 HEAT-T	105	.6941	21.23	20.47
	M469 HEAT-T	120	.9658	21.23	25.46
XM539E4	M409 HEAT	152	1.3323	126.45	107.93

Other fuze types on which independent variables were attempted to be used as cost predictors were MT and MTSQ. None of the variables attempted were acceptable. Therefore, use of analyses and engineering methods appear to be the only methods available for estimating these fuze types. The following relevant cost information regarding these fuzes and a proximity fuze is published to assist the estimator.

MT	Theoretical First-Unit Cost
M563	$186.73
XM571	376.35
XM592	450.19
XM711	365.48
MTSQ	
M548	208.23
M564	119.27
M577	208.94
Proximity	
M514A1	118.60

2. Variables Used in Regression Forms Initially Attempted

The following matrices reflect the independent variables which were initially to be used as cost predictors. The method employed was regression analysis using both linear and curvilinear forms. In some instances, several independent variables were used in combination, e.g. bore size and mass, and Ln bore size and Ln mass.

VARIABLES USED IN REGRESSION FORMS INITIALLY ATTEMPTED

DEPENDENT VARIABLES		Bore Size / Ln Bore Size	Bore Size & Prod Rate / Ln Bore Size & Ln Prod Rate	Proj Mass / Ln Proj Mass	Bore Size & Proj Mass / Ln Bore Size & Ln Proj Mass	Muzzle Vel / Ln Muzzle Vel	Bore Size & Muzzle Vel / Ln Bore Size & Ln Muzzle Vel	Bore Size Times Muzzle Vel / Ln Bore Size Times Ln Muzzle Vel	Momentum / Ln Momentum	Bore Size & Momentum / Ln Bore Size & Ln Momentum	Kinetic Energy (KE) / Ln KE	Bore Size & KE / Ln Bore Size & Ln KE	KE & Prod Rate / Ln KE & Ln Prod Rate	Bore Size, KE & Prod Rate / Ln Bore Size, Ln KE & Ln Prod Rate	Case Area / Ln Case Area	Bore Size, Mass & Case Area / Ln Bore Size, Ln Mass & Ln Case Area	Other / Ln Other
LOAD, ASSEMBLE & PACK (LAP)																	
All Rounds	Cost	X X	X X	X X					X X		X X		X X	X X			
	Ln Cost	X X	X X	X X					X X		X X		X X	X X			
HE Rounds	Cost	X X	X X	X X					X X		X X						
	Ln Cost	X X	X X	X X					X X		X X						
AP Rounds	Cost	X X	X X														
	Ln Cost	X X	X X														
TP Rounds	Cost	X X	X X	X X					X X		X X						
	Ln Cost	X X	X X	X X					X X		X X						
AP & TP Rounds	Cost	X X	X X	X X					X X		X X						
	Ln Cost	X X	X X	X X					X X		X X						
HE & AP Rounds	Cost	X X	X X	X X					X X		X X						
	Ln Cost	X X	X X	X X					X X		X X						
PROJECTILES																	Mass & Vel / Ln Mass & Ln Vel
HE Rounds	Cost	X X		X X	X X		X X		X X	X X	X X	X X					X X
	Ln Cost	X X		X X	X X		X X		X X	X X	X X	X X					X X
AP Rounds	Cost	X X		X X	X X												
	Ln Cost	X X		X X	X X												
TP Rounds	Cost	X X		X X	X X		X X		X X	X X	X X	X X					X X
	Ln Cost	X X		X X	X X		X X		X X	X X	X X	X X					X X
HEAT Rounds	Cost	X X		X X	X X												
	Ln Cost	X X		X X	X X												
CSTR Rounds	Cost	X X		X X	X X												
	Ln Cost	X		X X	X X												
HE & TP Rounds	Cost	X		X X	X X												
	Ln Cost	X		X X	X X												

VARIABLES USED IN REGRESSION FORMS INITIALLY ATTEMPTED

INDEPENDENT VARIABLES

	VARIABLE	Bore Size	Ln Bore Size	Bore Size & Prod Rate	Ln Bore Size & Ln Prod Rate	Prod Mass	Ln Prod Mass	Bore Size & Prod Mass	Ln Bore Size & Ln Prod Mass	Muzzle Vel	Ln Muzzle Vel	Bore Size & Muzzle Vel	Ln Bore Size & Ln Muzzle Vel	Bore Size Times Muzzle Vel	Ln Bore Size Times Ln Muzzle Vel	Momentum	Ln Momentum	Bore Size & Momentum	Ln Bore Size & Ln Momentum	Kinetic Energy (KE)	Ln KE	Bore Size & KE	Ln Bore Size & Ln KE	KE & Prod Rate	Ln KE & Ln Prod Rate	Momentum & Prod Rate	Ln Momentum & Ln Prod Rate	Case Area	Ln Case Area	Bore Size, Mass & Case Area	Ln Bore Size, Ln Mass & Ln Case Area	Other: Mass & Prod Rate	Ln Other: Ln Mass & Ln Prod Rate	Other: Bore & Lenses	Ln Other: Ln [illegible]
EXPLOSIVE FILL																																			
All Rounds	Cost							X	X																										
	Ln Cost							X	X																										
HE Rounds	Cost	X	X			X	X	X	X																										
	Ln Cost	X	X			X	X	X	X																										
HEAT Rounds	Cost	X	X			X	X	X	X																										
	Ln Cost	X	X			X	X	X	X																										
HEP Rounds	Cost	X	X			X	X	X	X																										
	Ln Cost	X	X			X	X	X	X																										
HE & HEP Rounds	Cost							X	X																										
	Ln Cost							X	X																										
CASES																																			
Brass	Cost	X	X	X	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Ln Cost	X	X	X	X	X	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Steel	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X					X	X	X	X			X	X
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X					X	X	X	X			X	X
PROPELLANTS	Cost	X	X			X	X					X	X	X	X	X	X			X	X														
	Ln Cost	X	X			X	X					X	X	X	X	X	X			X	X														
PRIMERS																																			
Percussion	Cost	X	X			X	X			X	X					X	X			X	X														
	Ln Cost	X	X			X	X	X		X	X					X	X	X	X	X	X	X	X												
Electric	Cost	X	X			X	X			X	X					X	X			X	X														
	Ln Cost	X	X			X	X		X	X	X					X	X		X	X	X		X												

VARIABLES USED IN REGRESSION FORMS INITIALLY ATTEMPTED

DEPENDENT VARIABLES		INDEPENDENT VARIABLES: Bore Size	Ln Bore Size	Bore Size & Prod Rate	Ln Bore Size & Ln Prod Rate	Proj Mass	Ln Proj Mass	Bore Size & Proj Mass	Ln Bore Size & Ln Proj Mass	Muzzle Vel	Ln Muzzle Vel	Bore Size & Muzzle Vel	Ln Bore Size & Ln Muzzle Vel	Bore Size Times Muzzle Vel	Ln Bore Size Times Ln Muzzle Vel	Momentum	Ln Momentum	Bore Size & Momentum	Ln Bore Size & Ln Momentum	Kinetic Energy (KE)	Ln KE	Bore Size & KE	Ln Bore Size & Ln KE	KE & Prod Rate	Ln KE & Ln Prod Rate	Bore Size, KE & Prod Rate	Ln Bore Size, Ln KE & Ln Prod Rate	Case Area	Ln Case Area	Bore Size, Mass & Case Area	Ln Bore Size, Ln Mass & Ln Case Area	Other	Ln Other
LINKS	Cost	X																															
	Ln Cost																																
FUZES																																	
PD Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
BD Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
PIBD Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
MTSQ Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
MT Fuzes	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
BD & PIBD	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
MTSQ & MT	Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										
	Ln Cost	X	X			X	X	X	X							X	X	X	X	X	X	X	X										

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F. TRANSPORTATION COSTS

Determination of transportation costs for ammunition items has long been a problem. Historically, these costs have often been forecasted with gross percentage adjustments based upon standard prices. At other times, attempts have been made to use complex deterministic cost models. Currently the Cost Analysis Division at ARMCOM is preparing a simplified regression approach to transportation cost modeling which will allow routine low-cost updating for economic changes, a feature not available in previous efforts. The data and analysis contained in this section are provided as a by-product of this larger ARMCOM study.

The data were prepared as follows: End items and quantities were chosen by the ARMCOM Transportation and Traffic Management Directorate from the FY-75 Shopping List as provided by the ARMCOM Maintenance Directorate (dated 11 Nov 74, and updated 3 Mar 75). The items were selected as being representative of items shipped during the third quarter of FY-75.

For each of the items selected, the interim transportation cost (from component manufacture to LAP plant) was restructured by determining the most-likely transportation path, the mode, and the shipping weight, and by applying the appropriate transportation rates in effect at the time of shipments. Actual billing data cannot be used because of the inability to make a reliable breakout of individual end-item costs from Government bills of lading. The second-leg transportation cost from the LAP plant to the CONUS depot or port of embarkation (POE) was developed in the same manner.

For purposes of this publication, the selected data were limited to fixed ammunition. Thus, the following dependent variables were extracted from the larger ARMCOM transportation study:

Cartridge Nomenclature	Unit Pounds As shipped	Per-Item-Interim Cost	Per-Item-Second-Leg Cost
5.56mm M193	0.041358	$0.0001	$0.0009
7.62mm M80	0.100938	0.0002	0.0023
20mm M220	0.988500	0.0127	0.0261
40mm M406	0.831790	0.0278	0.0334
40mm M407	0.812500	0.0290	0.0117
105mm M490	73.466667	1.1419	1.6738
105mm M393	71.166667	1.4744	2.3156
106mm M344	58.100000	0.3558	2.3871
106mm M346	63.000000	0.7181	2.5864

It is not reasonable to expect that the estimators will be able to use the unit-shipping weight as a cost driver because shipping weight is not available until the design is completed. Therefore, a proxy variable was obtained using projectile mass. The coefficient of determination between unit-shipping weight and projectile mass is 0.988. The cost data were regressed against projectile mass. The following table shows the coefficients of determination for the regression forms found to be appropriate for further consideration:

	FORMS		
	$Y = A + BX$	$Y = A\,X^B$	$\sqrt{Y} = A + B\sqrt{X}$
Interim	0.870	0.962	0.934
Second Leg	0.880	0.979	0.961
Total	0.976	0.997	0.992

Considering that in all cases the relationship of shipping cost to projectile mass is stronger at the total-cost level than at the interim and second-leg levels, only the total-cost level is appropriate for estimating.

The gap of actual data between 40mm and 105mm creates uncertainty in the development of any cost predictor. This data problem is a matter of specific inquiry and will hopefully be settled before publication of volumn II of the ammunition research project report.

Preferred predictor: Transportation

$$\ln Z = 1.5879 + 1.0140 \ln X \text{ or}$$

$$Z = 4.8933\,X^{1.0140}$$

where: Z = Estimated unit cost in FY-75 dollars
X = Projectile mass

Statistics:

Coefficient of determination = 0.997
Standard error of estimate in Ln form = 0.189
Mean absolute percent deviation = 15.2
Passes F test at 99 percent level of confidence
N = 9

CER DATA

Cartridge Nomenclature	Projectile Mass	Actual Unit Cost	Estimated Unit Cost
5.56mm M193	0.0002	$0.0010	$0.0009
7.62mm M80	0.0007	0.0025	0.0031
20mm M220	0.0071	0.0388	0.0324
40mm M407	0.0116	0.0407	0.0533
40mm M406	0.0116	0.0612	0.0533
106mm M344	0.5450	2.7429	2.6443
105mm M490	0.6941	2.8157	3.3791
106mm M346	0.5435	3.1045	2.6369
105mm M393	0.7705	3.7900	3.7566

A. NONRECURRING INVESTMENT

During an item's life cycle (LC) the first IPCE is required prior to the first Army System Acquisition Review Council (ASARC-1) decision point. IPCE-I contains, among other cost elements, an estimate for IPF. The Project Manager for Munitions Production Base Modernization and Expansion, who has the responsibility for IPF, first enters the LC process of events through his involvement with producibility engineering and planning (PEP). This event occurs just after the second Defense Systems Acquisition Review Council (DSARC-2) decision point. The time between the IPCE-1 and PEP could be several years and the lack of a coordinated IPF effort could be detremental to the research and development program, since the IPF could inadvertently be grossly over or under stated in the IPCE.

An additional and directly related problem of mobilization base requirements (MBR) exists. The IPF estimate is sensitive to MBR or total ammunition quantity, mix, and annual acquisition rate. This quantitative information is required by both the system proponent and the IPE estimator piror to IPCE-1. Therefore, a timely and coordinated MBR statement is essential to realistic estimates prepared for the ASARC and DSARC. The MBR statement significantly affects cost elements in the investment recurring cost category.

It is recommended that the appropriate agencies be required to staff and resolve the problems cited above. It may be necessary to establish the mobilization plan as a requirement for completion of the decision coordinating paper.

B. ECONOMIC ORDER QUANTITY DETERMINATION

Following procurement of ammunition to fulfill the Authorized Acquisition Objective (AAO) and deployment of the user system to the field, consumption and replenishment of the training and practice ammunition inventory occur on a continuing, periodic basis to meet individual and unit training and service practice requirements. It is because of the long-term demand and resulting high-volume procurement of the latter requirements that the economics of order quantities becomes an important consideration. Investigation has revealed that current practice remains to base the procurement of operating ammunition of inventory drawdown, budget constraints, or both. Thus, to a large degree, the determination of order quantities is subjective rather than deterministic.

Ammunition experts agree that ammunition storage (inventory maintenance) costs can represent a significant element of expense. Storage costs can be reduced by maintaining lower average levels of inventory, but procurement related costs incurred by more frequent reordering of smaller quantities tend to offset the reductions obtained. Although the annual demand or consumption rate of training and practice ammunition may be relatively precise, the procurement pattern can

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theoretically range from annual orders to meet the demand rate of procurement of the full life-cycle requirement in one order. Hence, the problem is to achieve a balance between procurement related and inventory related costs by means of varying the quantity ordered. This is a classic case of cost minimization.

A generalized inventory model, based on relevant summary-level costs, is presented below to illustrate the economic order-size concept. The model is shown graphically in Figure 1. The cost symbols used are defined as follows:

q = quantity (number of rounds) per order.

I = inventory related cost; i.e., the cost of holding one round in inventory for a unit of time. This factor may include the costs incurred in the provision and maintenance of storage facilities, physical maintenance of the inventory, and losses caused by obsolescence or damage experienced over time.

T = total time over which the training and practice ammunition is planned for procurement.

Q = the total number of rounds required over the time period T.

S = procurement related cost; i.e., the indirect cost per order incurred each time an order is procured (excluding price per round). This factor may include the administrative costs to place an order, the production setup costs per order and the indirect cost of production breaks (line shutdown, standby and line maintenance).

TC = total relevant cost; i.e., the sum of the procurement related and inventory related costs per order.

qm = economic order quantity; i.w., the order quantity at which the total cost, TC, is a minimum.

Given that Q rounds are required, the number of orders placed during time T is Q/q. If t is the time interval between orders, it follows that

1. $$t = \frac{T}{Q/q} = \frac{Tq}{Q}$$

The model assumes that q rounds are in inventory at the beginning of the time interval t, and that the inventory is depleted at the end of the interval. Based on this assumption, the average inventory level during the time t is q/2. Hence, the inventory related cost per order is the average inventory level multiplied by the inventory related cost per round per unit of time multiplied by the time interval t, or

2. Inventory related cost per order = $q/2$ It

The time interval t can be expressed in terms of the total time T by substituting the right-hand side of equation for t in equation 2.

3. Inventory related cost per order = $\frac{q^2 \ IT}{2Q}$

The total inventory related costs over the time period T is determined by multiplying the cost per order equation 3 by the number of orders placed over time T, or Q/q.

4. Total inventory related costs = $\frac{q^2 \ ITQ}{2Qq}$ = IT (q/2)

The total procurement related cost over the time period T is the procurement related cost per order, S, times the number of orders, Q/q.

5. Total procurement related cost = S(Q/q)

The total cost, TC, is the sum of the total inventory related cost, equation 4, and the total procurement related cost, equation 5, or

6. $TC = IT(q/2) + S\ (Q/q)$

The two right-hand terms in the total cost equation are shown graphically in Figure 1, in which the total inventory related cost increases with increases in order quantity and the total procurement related cost decreases with increases in order quantity. Graphically, the most economic order quantity is that quantity at which the curves for these costs cross, i.e., the minimum point of the total cost curve. Mathematically this quantity can be determined by the process of differential calculus, in which the first derivative of the total cost equation 6 is set equal to zero. As a result of this process, the economic order size is determined to be

7. $qm = \frac{2QS}{TI}$

Models of the foregoing type are, for presentation purposes, general in nature and are based on several assumptions. The model described assumed the following:

a. The price per round is independent of order size, and can be excluded from the model. To the extent that the results of this study indicate that learning is not lost during production breaks, this assumption is true, however, other affects on price, such as inflation or quantity

discounts for material, may render the assumption only partially true.

b. The demand rate is known with certainty and is constant over time T.

c. The procurement related cost per order is constant.

d. The inventory related cost varies linearly with the level of average inventory.

e. Procurement leadtime is a constant; i.e., stockouts (or depletion of inventory below a prescribed level) are not permissable.

f. The average inventory level is q/2 as described above.

Inventory models like this and similar to this are developed in a variety of management and production related publications, of which reference 52 is typical. However, since the assumptions on which such models are based may not be exact in practice, and the relevant costs in a general model are not explicitly defined, application requires extensive study and tailoring to accommodate the solution of actual inventory problems. Because the cost penalty of subjective order quantity determination may be significant over the life cycle of a given family of ammunition, it is recommended that a separate study be considered to:

(1) evaluate the feasibility of procuring training and practice ammunition in economic order quantities, and of identifying and quantifying the relevant costs.

(2) develop model(s) to determine the economic order quantity for specific applications.

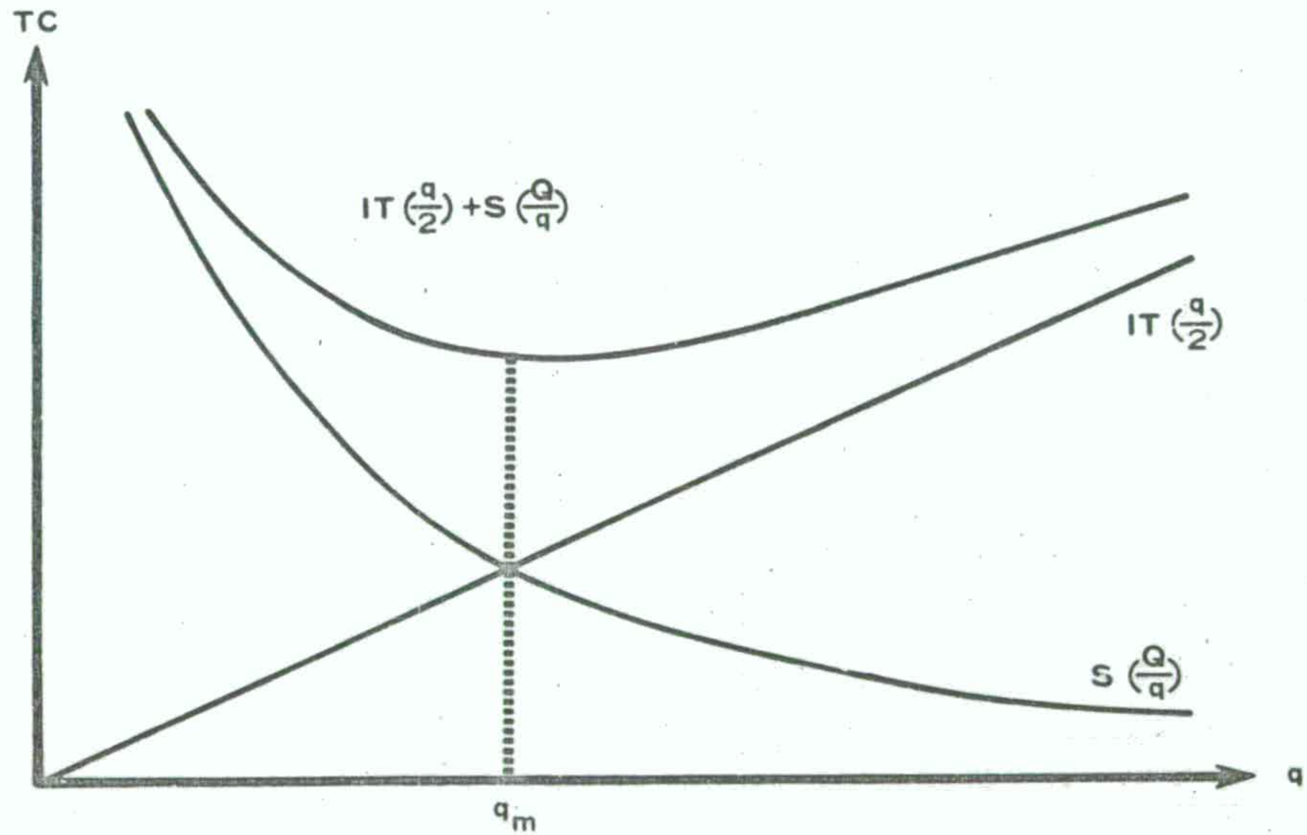

FIGURE 1 VARIATION OF TOTAL COST WITH ORDER QUANTITY

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